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TWENTIETH CENTURY TEXT-BOOKS

# PHYSICAL EXPERIMENTS

## A LABORATORY MANUAL

BY

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# PROPERTIES OF MATTER AND MECHANICS OF SOLIDS

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  3. *Capillarity.*
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  4. *Diffusion of Liquids.*
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  6. *Osmose.*
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  7. *Crystallization.*
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# I. EXTENSION AND WEIGHT OF MATTER

**Exercise 1.**—To determine the ratio between an inch and a centimeter.* Measure the line (Fig. 1) in inches to the hundredth part, and in centimeters to the quarter of a millimeter.

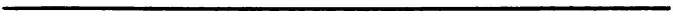

Fig. 1.

Express the result decimally and in the following form :

.... in. = .... cm.

From this result calculate results for the following :

(a) 1 in. = .. cm.
(b) .. in. = 1 cm.
(c) .. in. = 100 cm. (1 meter).

**Exercise 2.**—To determine the ratio between a meter and an inch. Measure the given line (to be supplied in the laboratory) in meters and in inches. Express the result as follows :

.... m = .... in.

Calculate results for the following :

(a) 1 m. = .. in.
(b) .. cm. = 1 in.
(c) 1 cm. = .. in.

Compare these results with those obtained in the former exercise. Which are probably more nearly correct ? Why ?

---

* Always draw along the edge of the ruler on which there is no scale. In making measurements turn the ruler upon edge, so that the scale touches the paper.

Exercise 3.—To determine the ratio between an ounce and a gram. Place an ounce weight or some multiple of an ounce upon the scale pan. Balance it by gram weights to the tenth part of a gram. Express the result as follows:

.... oz. = .... gm.

Calculate the results for the following:

(a) 1 oz. = ... gm.
(b) .. oz. = 1 gm.
(c) 1 lb. = ... gm.
(d) .. lb. = 1 kg. (1,000 gms.).

Exercise 4.—To determine the ratio between a quart and a liter. Measure a quart, pint, or half pint of water, and find how many cubic centimeters it is equal to. Express the result as follows:

.... qt. = ... c. c.

Calculate the following:

(a) 1 qt. = .... c. c.
(b) .. qt. = 1,000 c. c. (1 liter).

Exercise 5.—To determine the weight of a cubic centimeter of water in grams. Place a measuring glass upon the scales and balance it. Pour in water to any depth, weigh the water in grams, and read the volume in cubic centimeters. Add more water. Read the volume and add weights to restore the balance. Repeat several times. Express the results as follows:

First trial .... c. c. of water weigh .. gm.
Second trial .... c. c. of water weigh .. gm.
Third trial .... c. c. of water weigh .. gm.
Total .... c. c. of water weigh .. gm.

Calculate the following:

(a) 1 c. c. of water weighs .. gm.
(b) 1 liter of water weighs .. gm.

# II. PROPERTIES OF MATTER

## 1. Cohesion and Adhesion.

EXPERIMENT 6.—Wet two plates of glass and press them together. Pull them apart again. Try to keep their faces parallel while doing so. Touch one of them to the surface of water. Lift it from the water. Try to keep its face parallel to the surface of the water while doing so. Try other liquids, such as mercury, oil, etc. Discuss this experiment rather fully.

Is it generally easier to separate the liquid from the solid, or the liquid from the liquid?

Gluing and cementing.
Welding of metals. Soldering.
Solid, liquid, and gaseous state of matter.

## 2. Porosity.

EXPERIMENT 7.—Put water into a test-tube to the depth of about an inch. Then slowly add about an inch of alcohol. Measure the height of liquid in the test-tube. Shake them well together and measure again. Explain.

EXPERIMENT 8.—Hold a piece of blackboard crayon under water. Why do air bubbles rise to the surface?

Wood, sponge, leather, pumice stone.

### 3. Capillarity.

Draw out some glass tubing into capillary tubes of various sizes.

EXPERIMENT 9.—Put them into cold water; into hot water; into alcohol; into mercury. How is capillarity affected by the size of the tube, by temperature, and by the kind of liquid used?

EXERCISE 10.—Explain the appearance of the surface of water in a U-tube three sixteenths of an inch in diameter. Explain the appearance of the surface of mercury in the same tube.

Candles and lamp wicks.
Blotting paper.
Sponges.
Loaf sugar.

### 4. Diffusion of Liquids.

EXPERIMENT 11.—Invert a test-tube filled with water in a small tumbler containing copper sulphate. Allow it to stand several days.

### 5. Diffusion of Gases.

EXPERIMENT 12.—Invert a wide-mouthed bottle of hydrogen over one of oxygen. After they have stood for several minutes bring a flame to the mouth of each. Explain.

Nitrogen is lighter than oxygen. Why are they not in layers in the atmosphere?

### 6. Osmose.

Experiment 13.—Put a concentrated sugar solution into a test-tube to the depth of about two inches. Tie a piece of gold-beater's skin over the mouth, and invert it in a small tumbler of water. Crack a hole in the upper end of the test-tube. Allow the apparatus to stand for several days, and notice what happens.

Experiment 14.—Tie gold-beater's skin over the bottom of an Argand lamp chimney. Fill the chimney with concentrated copper-sulphate solution as far as the constriction. Support the chimney to this depth in a tumbler of water. In which direction is the greater flow?

Rising of sap in trees.

### 7. Crystallization.

Experiment 15.—Fill a test-tube half full of ammonium chloride. Add water so that the tube shall be about two thirds full, heat until the ammonium chloride is dissolved. Allow the solution to cool slowly, and watch the crystals form.

Experiment 16.—Dissolve 50 grams of alum in 50 grams of hot water. Examine the crystals which form on cooling.

Experiment 17.—Make a saturated solution of copper sulphate. Allow the solution to cool, and examine the crystals.

Experiment 18.—Heat some small pieces of roll brimstone until they have melted to a straw-colored liquid. Examine the crystals which form on cooling.

Experiment 19.—Dissolve some flower of sulphur in a little carbon bisulphide. Cover the solution and set it aside to evaporate, and compare the sulphur crystals obtained by this method with those obtained by melting the sulphur.

EXPERIMENT 20.—Fill a one-ounce narrow-mouthed bottle with water, cork it, and surround it with a freezing mixture of salt and ice. Allow it to stand fifteen or twenty minutes, until the bottle cracks. Uncover carefully to see what has happened to the cork.

Crystallization of water, type metal, etc.

### 8. **Viscosity.**

EXPERIMENT 21.—Melt some small pieces of roll brimstone in a test-tube. Then gradually raise the temperature of the melted sulphur to such a point that the test-tube may be inverted.

EXPERIMENT 22.—Support a stick of sealing wax or a paraffin candle at either end in a horizontal position, and leave it for several weeks or months until it becomes permanently bent.

Perfect rigidity, viscosity, perfect mobility.
Balsam, molasses, honey, pitch, asphalt, concrete walks.

### 9. **Elasticity.**

EXPERIMENT 23.—Measure a piece of elastic. Stretch and release, then measure again. Repeat several times. What is meant by perfect elasticity?

EXPERIMENT 24.—Draw a piece of glass rod out into fine threads. Notice their elasticity upon bending.

Elastic force of gases.
Tempered steel.
Steel springs.
Spring balances.

### 10. **Malleability.**

EXPERIMENT 25.—Pound a piece of lead into a thin sheet. Flatten melted glass by pressing it between forceps.

Gold leaf.

# III. MECHANICS OF SOLIDS

**The Pendulum.**

EXPERIMENT 26.—Determine whether time of vibration is independent of length of arc (amplitude of vibration).

Use a pendulum (a wooden or glass ball attached to a thread is convenient) about 18 inches long,* and count the number of swings it makes in a minute through arcs of various lengths.

EXPERIMENT 27.—Determine whether time of vibration is independent of the weight of the ball. Use balls of various sizes and weights.

EXPERIMENT 28.—Determine the length of a pendulum that will swing 60 times a minute. Begin with one about 1 meter long.

EXPERIMENT 29.—Determine how the length of the pendulum is related to the time of vibration. Start with a pendulum about 24 inches long. Count the number of swings it makes in a minute. Make it 6 inches long, and record as before.

What are the laws governing the pendulum?

EXERCISE 30.—Determine the height of the ceiling of your laboratory by counting (per minute) the number of swings of a pendulum suspended from there. Add to the result which you obtain the height of the middle of the ball from the floor.

The metronome, clocks.

---

* The length should be measured from the *middle* of the ball.

## Second Law of Motion.

EXPERIMENT 31.—Determine by means of the apparatus represented in Fig. 2 whether an object projected horizontally will reach the floor in the same time as one let fall vertically from the same height.

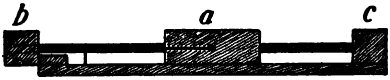

FIG. 2.—Apparatus for illustrating second law of motion.

Fig. 2 represents a thin strip of wood to which is fastened a small block (*a*). Through this block passes a dowel rod as long as the strip. *b* and *c* represent two blocks, through one of which (*b*) a hole is bored to fit the dowel rod. By means of rubber bands the dowel rod sets both blocks free to fall at the same instant, but projects one horizontally and the other vertically.

Inertia.
Stable, indifferent, and unstable equilibrium.
Gravity.

## Uniformly Accelerated Motion.

EXPERIMENT 32.—Arrange a trough in front of a blackboard in such an inclined position that a ball set to rolling will go say 1 foot during the first second. (The time may be marked by a pendulum which swings once a second.) The unit distance which the ball travels the first second may be marked on the blackboard.

Determine whether the ball will go three, five, and seven times as far during the second, third, and fourth seconds as during the first second.

### The Path of Projectiles.

EXERCISE 33.—To the scale of $\frac{1}{16}$ inch to 16-feet, plot the path of a ball thrown upward in such a manner that it will have a vertical velocity of 256 feet per second, and at the same time a horizontal velocity of 48 feet per second. Designate your sketch as Fig. 3.

What will be the length of the whole distance traveled? How many seconds will it take to travel this distance? How long would it take the same ball to reach the ground if it were thrown merely with a vertical velocity of 256 feet per second?

### Moments of Force and Machines.

EXPERIMENTS 34 AND 35.—Determine by means of the apparatus illustrated in Figs. 4 and 5 what forces must be supplied to produce equilibrium in several of the cases represented in Figs. 6–28. From these trials deduce principles which will apply to all the cases represented.

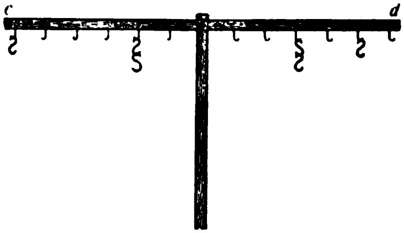

FIG. 4.—Apparatus for illustrating moments of force.

Fig. 4 represents a strip of wood, on which is pivoted a strip, *c d*, which swings freely. The weights which are hung from *c d* by means of bent pins may be made of pieces of stout copper wire, cut into equal lengths and bent into convenient shapes for hanging.

Fig. 5 represents a strip of wood, *m n*, containing several tacks, to which spring balances may be attached by means of threads. The apparatus is used horizontally upon a table.

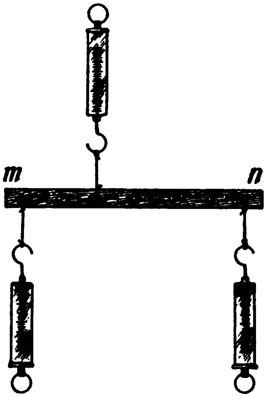

Fig. 5.—Apparatus for illustrating moments of force.

In the following exercises (36–57) certain of the forces are given in each case, and it is required to determine the remainder. It should be first calculated according to the principles, and the result afterward verified by using the apparatus represented in Figs. 4 and 5.

EXERCISE 36.

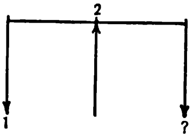

Fig. 6.

EXERCISE 37.

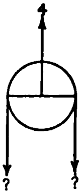

Fig. 7.

### EXERCISE 38.

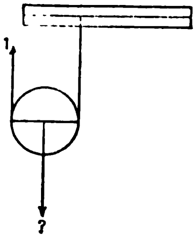

FIG. 8.

### EXERCISE 39.

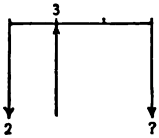

FIG. 9.

### EXERCISE 40.

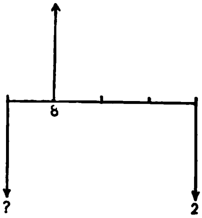

FIG. 10.

### EXERCISE 41.

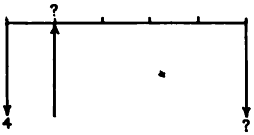

FIG. 11.

### EXERCISE 42.

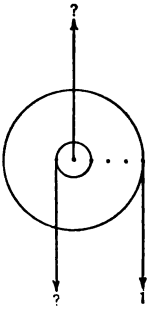

FIG. 12.

### EXERCISE 43.

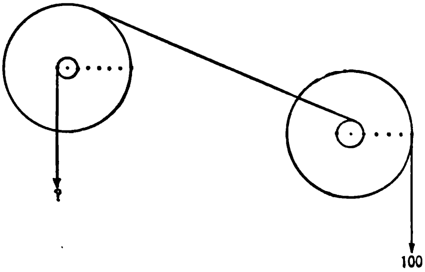

FIG. 13.

### EXERCISE 44.

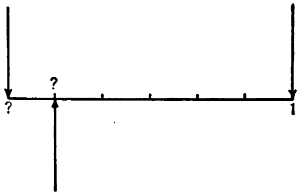

FIG. 14.

### EXERCISE 45.

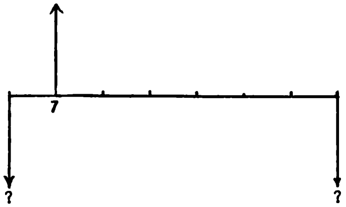

FIG. 15.

### EXERCISE 46.

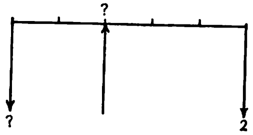

FIG. 16.

### EXERCISE 47.

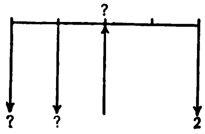

FIG. 17.

### EXERCISE 48.

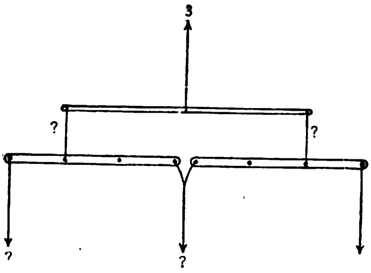

FIG. 18.—Whiffletrees for three horses abreast.

### EXERCISE 49.

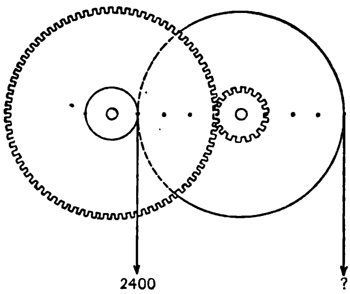

FIG. 19.—Cogwheels.

### EXERCISE 50.

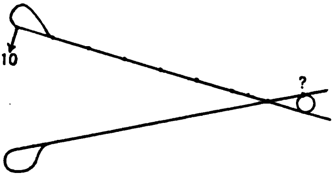

FIG. 20.—Long-handle shears for cutting metal.

### EXERCISE 51.

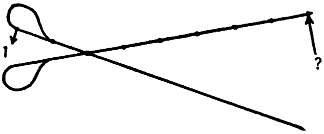

FIG. 21.—Short-handle shears for cutting paper.

### EXERCISE 52.

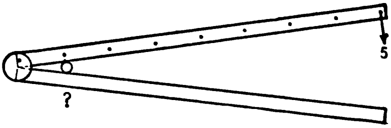

FIG. 22.—Nut-cracker.

### EXERCISE 53.

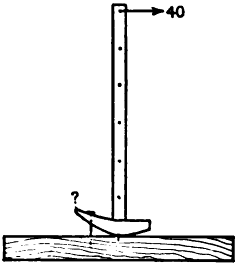

FIG. 23.—Hammer.

EXERCISE 54.—Fig. 24 represents a log of wood, the weight of which is 200 pounds. What force would be required at *a* or *b* or *c* to *start* to lift it?

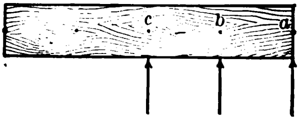

FIG. 24.

Exercise 55.—Compare forces *a* and *b* in Figs. 25 and 26 necessary to *start* the motion of the box.

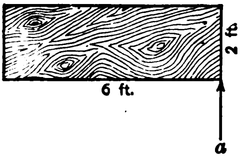

Fig. 25.

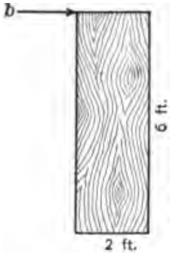

Fig. 26.

Exercise 56.—Fig. 27 represents a block of granite 2 × 4 × 8 feet. The specific gravity of granite is about 2.5. A cubic foot of water weighs 62.5 pounds. The bar, *a*, is 10 feet 4 inches long, and the fulcrum is 4 inches from the block. What force must be applied at *P* to move it?

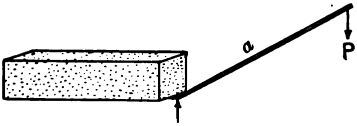

Fig. 27.

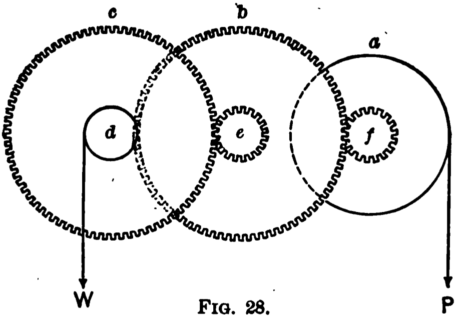

Fig. 28.

EXERCISE 57.

Diam. of $a = 6$ in. Diam. of $d = 2$ in.
" " $b = 8$ " " " $e = 2$ "
" " $c = 8$ " " " $f = 2$ "

(1) How many times as many cogs in the circumference of $b$ as in that of $f$?

(2) How are the number of revolutions in $a$ and $c$ to be compared?

(3) What weight at $W$ will balance 100 at $P$?

### QUESTIONS AND PROBLEMS

1. Explain why a stream of water falling freely tends to separate into drops.

2. Why should one, in getting off and on a moving car, face the front of the car?

3. Why are steel springs used in the "spring balances"? Upon what does the efficiency of such a balance depend?

4. Why is an empty car in motion more easily stopped than a loaded one?

5. How long will it take a ball thrown upward with a vertical velocity of 192 feet per second to reach the ground?

6. Suppose a body weighing 10 pounds moves under the influence of a constant force 20 feet the first second, 60 feet the next second, and 100 feet the third second, how far will it move the fourth second? How does its momentum at the end of the fourth second compare with that at the end of the second second? Explain your method of calculation.

7. If a pendulum which swings once a second is 39 inches long, find the length of a pendulum which swings 20 times a minute.

8. How may the vibrations of a pendulum be quickened fourfold?

9. In a certain wheel and axle the diameter of the wheel is 4 feet and that of the axle is 1 foot. It is found that on account of friction a weight of 160 pounds attached to the rope which encircles the wheel is necessary to lift a weight of 600 pounds attached to the

rope which encircles the axle. How much work must a man do to lift the 600 pounds a distance of 2 feet with this machine? How much work would he need to do to lift it without the machine?

10. Why are long-handled shears used in cutting metal?

### TABLE OF EQUIVALENTS

1 in. = 2.54 cm.
1 cm. = .3937 in.
1 m. = 39.37 in.
1 oz. (av.) = 28.35 gms.
1 liter = 1,000 c. c.
1 qt. (liquid) = 946 c. c.

# MECHANICS OF FLUIDS

I. PRESSURE IN LIQUIDS.

*Preliminary Exercises.*

Exercises 1, 2, 3, and 4. Figs. 1 and 2.

*First Principle.*

Experiments 1, 2, and 3. Exercises 4 and 5. Figs. 3, 4, 5, and 6.

*Buoyancy and Specific Gravity.*

Experiments 6, 7, 8, and 9. Figs. 7, 8, and 9.

II. PRESSURE IN GASES.

*Second Principle.*

Experiments 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19. Figs. 10, 11, 12, 13, 14, and 15. A, B, C, D, E.

*Boyle's Law.*

Experiment 20. Figs. 16 and 17.

III. PRESSURE TRANSMITTED.

*Third Principle.*

Experiments 21 and 22. Figs. 18, 19, and 20.

IV. MISCELLANEOUS APPLICATIONS.

*Cartesian Diver.*

Exercise 23. Fig. 21.

*Siphon.*

Exercise 24. Figs. 22, 23, 24, and 25.

*Fountain Siphon.*

Exercise 25. Fig. 26.

*Lifting Pump.*

Exercise 26. Fig. 27.

*Force Pump.*

Exercise 27. Fig. 28.

*Specific Gravity of Liquids.*

Exercise 28. Fig. 29.

*Pressure in a Barometer Tube.*

Exercise 29. Fig. 30.

*Hero's Fountain.*

Exercise 30. Fig. 31.

*Student's Lamp.*
Exercise 31. Fig. 32.
*Fountain Sponge Cup or Ink Well.*
Exercise 32. Fig. 33.
*Constant Pressure.*
Exercise 33. Fig. 34.
*Pressure Gauges in Series.*
Exercise 34. Fig. 35.
Questions and Problems.
Table of Specific Gravities, Weights, Equivalents, etc.

# I. PRESSURE IN LIQUIDS

## Preliminary Exercises.

EXERCISE 1.—To find the relative weight of water and mercury. Measure the length of the water column *a b* (Fig. 1). Measure the height of the mercury column *b c*, which balances the water column. Compute the relative weight of water and mercury.

The following method is convenient for recording the results:

Length of water column *a b* = .... centimeters.

Length of mercury column *b c* = .... centimeters.

.... centimeters of mercury weigh as much as .... centimeters of water, therefore 1 centimeter of mercury weighs as much as .... centimeters of water. Mercury is .... times as heavy as water.

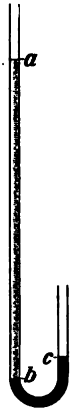

FIG. 1.

EXERCISE 2.—To find the relative weight of alcohol and mercury. Proceed as in the former exercise, calling the length of the alcohol column *a b*, and the length of the mercury column which balances it *b c*.

EXERCISE 3.—From the results obtained in the previous exercise calculate the relative weight of water and alcohol.

Mercury is .... times as heavy as water.

Mercury is .... times as heavy as alcohol.

Water is .... times as heavy as alcohol.

Alcohol is .... times as heavy as water.

**Exercise 4.**—To find the relative weights of alcohol and water. Measure the length of the alcohol column, *c b* (Fig. 2). Measure the length of the water column, *a b*, which balances it. Compute the relative weights of alcohol and water. Compare the results with those obtained in Exercise 3. Which are probably more nearly correct? Why?

### Questions.

Suppose that in Exercise 1 it were found that 1 centimeter of mercury balanced 13.6 centimeters of water. Imagine the cross section of the tube (Fig. 1) to be 1 square inch, how many cubic inches of water will it take to weigh as much as 1 cubic inch of mercury? One cubic inch of mercury weighs about $\frac{1}{2}$ pound, about how much does 1 cubic inch of water weigh? One cubic centimeter of water weighs 1 gram, what is the weight of 1 cubic centimeter of mercury?

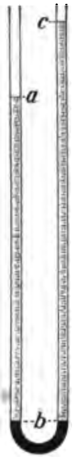

Fig. 2.

**Principle I**

(*a*) *Pressure in liquids is proportional to the depth without regard to the size or shape of the vessels which contain them.* (*b*) *At any given depth it is equal in all directions.*

(*a*) Find the ratio of pressure to the depth of the water in the three given pieces of apparatus.

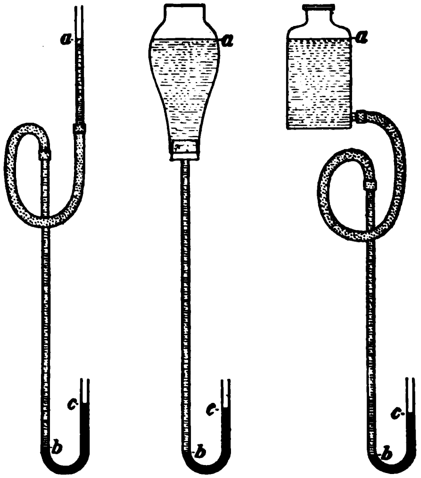

FIG. 3.

EXPERIMENT 1.—Measure the length of the mercury column *b c* (Fig. 3) in each of the three pieces of apparatus. Using for the relative weight of water and mercury the class average from Preliminary Exercise 1. (Why is this better for your use than the standard ratio?) Calculate what length of water column in each case would be necessary to balance the mercury column *b c*. Measure the length of the water column *a b* in each case. Compare these measurements with the calculated results and record the errors.

**Experiment 2.**—(*b*) Find the pressure downward, sidewise, and upward at a given depth—say 20 centimeters—in water in terms of centimeters of mercury.

Let the depth of the water column, *a b* (Fig. 4), in each case be 20 centimeters. Measure the length of the mercury column (*b c*), which balances this water pressure. Calculate the length of mercury column necessary to balance a water column 20 centimeters long.

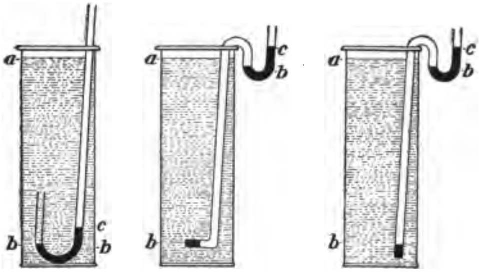

Fig. 4.

**Experiment 3.**—Close the lips tightly over one end of a pressure gauge, and find how long a column of mercury you can support by steady pressure of air from your lungs. How long a column of water would this pressure support? How many grams per square centimeter would this pressure support?

A cubic inch of mercury weighs about half a pound; how many pounds per square inch would this pressure support? Was this the outward pressure upon the walls of your chest and mouth during this exercise?

Exercise 4.—The vessel (Fig. 5) is filled with water. What is the pressure per square centimeter at the points *a*, *b*, *c*, *d*?

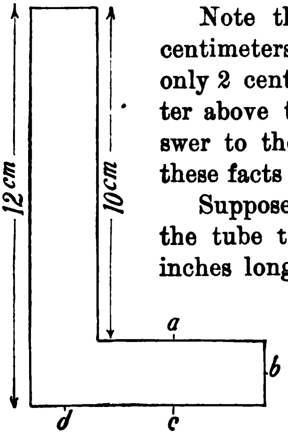

Fig. 5.

Note that *d* has a column of water 12 centimeters long standing over it, while *c* has only 2 centimeters and *b* 1 centimeter of water above them. Can you explain your answer to the above question in the light of these facts?

Suppose the area of the cross section of the tube to be 1 square inch. How many inches long would a column of water have to be to exert a pressure of ½ pound at *d*? How long a column of mercury would exert this pressure?

Exercise 5.—Three vessels (Fig. 6) have all the same depth—10 centimeters. They are filled with water. What is the pressure per square centimeter upon the bottom of each? The bottom of each has an area of 100 square centimeters. What is the total pressure upon the bottom of each? Is the weight of water in each the same?

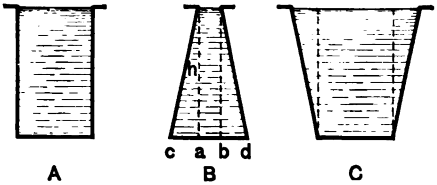

Fig. 6.

**Problems.**

1. A mercury pressure gauge is attached to the bottom of a tank of water. The pressure is found to be sufficient to hold up a column of mercury 15 inches. How many pounds pressure per square inch does this represent? How high is the water in the tank?

2. If the average lung pressure is 1½ pounds per square inch, how many centimeters high would it be possible to support a column of mercury in Experiment 3? How many grams pressure per square centimeter would this represent?

## Buoyancy and Specific Gravity.

EXPERIMENT 6.—Find the area of the cross section of the specimen tube (Fig. 7). (Measure the diameter of the tube in centimeters, and compute the area of its cross section according to the formula $\pi r^2$.) Measure in centimeters *a b*, the depth to which the tube sinks in the water. What is the upward pressure upon each square centimeter of the bottom of the tube? What is the total pressure? This is the buoyant force. From this calculate what must be the weight of the tube with the shot which it contains, and the volume of the water which it displaces. Find the weight by using the balance. Find the volume of water it displaces by floating it in a graduate cylinder.

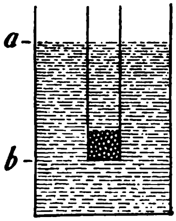

FIG. 7.

## Corollaries.

A floating body displaces its own weight of the liquid. A body that sinks displaces its own volume of the liquid. The buoyant force equals the weight of the floating body. The buoyant force equals the weight of the liquid displaced. The buoyant force at any given depth is the upward pressure at that depth.

Experiment 7.—Weigh the marble (Fig. 8) in air. Weigh it when suspended in water. How much does the water buoy up? What is the volume of the marble? What is its weight compared with that of an equal volume of water? (Specific gravity.)

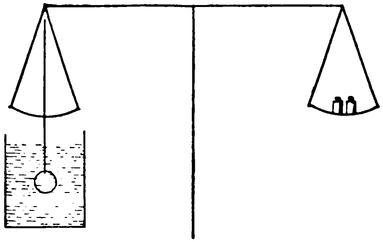
Fig. 8.

Experiment 8.—Find the volume of the marble used in the previous exercise by immersing it in a test-tube containing water, and computing, according to the formula $\pi r^2 \times h$, the volume of the cylinder of water displaced. Compare the result with that obtained in the previous exercise. Which is more reliable? Why?

Experiment 9.—Weigh a marble. Balance a tumbler of water (Fig. 9) upon a scale pan. Then suspend the marble in the water so as not to touch the bottom or sides of the tumbler, but have it completely submerged. Find how much weight must be added to the other scale pan to restore the balance. How much did the water buoy up? How much did the thread sustain? What is the volume of the marble? What is its specific gravity?

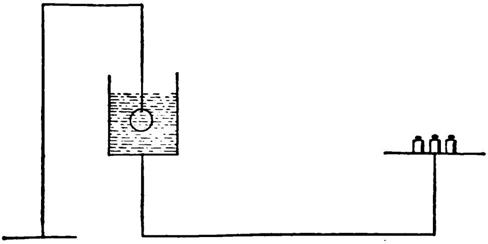
Fig. 9.

**Problems.**

1. Given a canal boat about like a box in shape. If the area of the bottom is 300 square feet, and it sinks 2 feet into the water, what must be its weight? What load would be required to sink it to a depth of 5 feet? One cubic foot of water weighs about 62.5 pounds.

2. A cubic inch of mercury weighs ½ pound. Its specific gravity you have already found. (*a*) Find the pressure of the water in pounds per square inch at the bottom of a rectangular aquarium by measuring its depth. (*b*) What is the total pressure upon one of its sides?

3. How many pounds would it be necessary to lift in moving a stone under water, if the volume of the stone were 1 cubic foot and its specific gravity 2.5? If the same stone were immersed in sulphuric acid of specific gravity of 1.8, what would be its apparent weight?

4. If the specific gravity of a certain object is 2, what is its weight if it displaces 25 cubic centimeters of water?

5. If a block of wood 2 × 2 × 4 feet has a specific gravity of .5, how much will it need to be loaded in order to just submerge it in water? If you attach a load to the block you will increase its volume. What will you do with that fact? How much granite, specific gravity 2.5, would be required to sink the block?

# II. PRESSURE IN GASES

**Principle II.**

*Pressure of the air increases with, but is not proportional to, the depth. At any given depth it is equal in all directions.*

EXPERIMENT 10.—Show by the balances that air has weight. Suspend from one pan of the balances an eight-ounce flask containing a rubber stopper with one hole. By means of a piece of glass tubing in the hole of the stopper, attach a small piece of rubber tubing containing a plug. Balance carefully. Remove the plug, and by means of the lungs or an air pump exhaust air from the flask. Pinch the rubber tube and replace the plug. The flask should show a decrease in weight. Add weights to restore the balance. Then detach the flask from the scale pans, invert the flask over water, and remove the plug. Measure in a graduate glass the volume of water that rises into the flask. Record the result as follows:

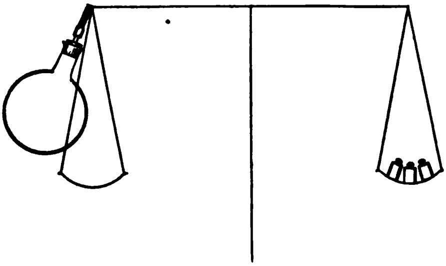

FIG. 10.

.... c. c. air weigh .... gms.

Water is 773 times as heavy as air. Compute the weight of the volume of air obtained in your experiment, and compare with the result obtained. The weight of a liter of air is about 1.29 grams.

EXPERIMENT 11.—Cause a fountain to play by atmospheric pressure, as represented in Fig. 11. By means of the lungs or an air pump exhaust air from the bottle, and then invert the bottle, allowing the rubber tube to dip into water. A fountain will play in the bottle ("fountain *in vacuo*").

EXPERIMENT 12.—Lift the bottle (Fig. 12) by the lamp chimney after exhausting air from it. This chimney merely rests upon a rubber stopper. How does the experiment illustrate the pressure of the air?

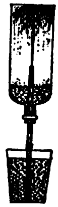

FIG. 11.

Magdeburg hemispheres.

EXPERIMENT 13.—By means of the barometer (Fig. 13) find the pressure of the air. Read it on several successive days, and compare with the newspaper reports.

Why does a column of mercury 30 inches high represent a pressure of about 15 pounds per square inch? How many centimeters high must a column of water be to represent the same pressure? How many grams pressure per square centimeter does this indicate? Why may we not calculate the height of our atmosphere from this pressure? If the pressure of the air were proportional to the depth, how high would the atmosphere be to support a column of mercury 30 inches high?

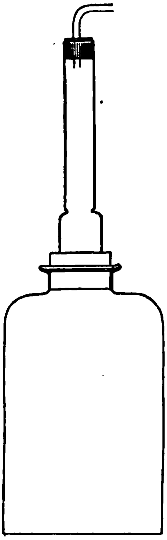

FIG. 12.

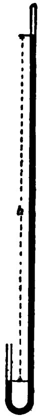

FIG. 13.

Illustrate the expansive force of the air by using the pieces of apparatus illustrated in Figs. 14 and 15, *A–E*.

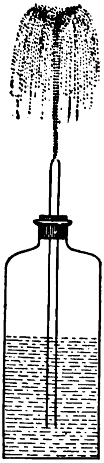

FIG. 14.

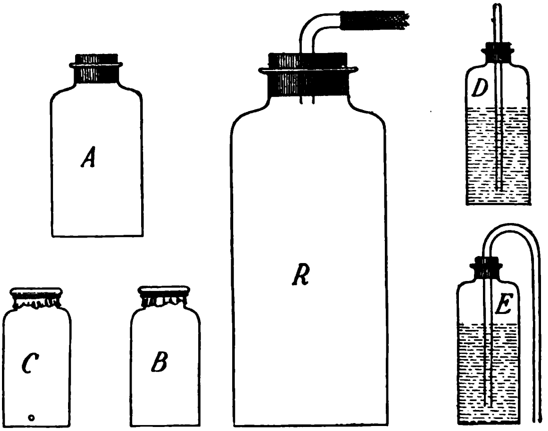

FIG. 15.

EXPERIMENT 14.—Cause a fountain to play by first condensing air in the bottle (Fig. 14) and then removing the pressure.

EXPERIMENT 15.—Close the mouth of the bottle (Fig. 15, *A*) with a rubber stopper. Put the bottle into the receiver *R*, and pump air from the receiver. Explain what occurs.

EXPERIMENT 16.—Rubber cloth is tied over the mouth of the bottle (Fig. 15, *B*). Put it into the receiver *R*. First condense air and then exhaust air, and explain what happens in each case.

EXPERIMENT 17.—Rubber cloth is tied over the mouth of the bottle (Fig. 15, *C*) and in the side of it a small hole has been bored. Try the effect on the rubber cloth of condensing and rarefying the air in the receiver *R* when the hole in the small bottle is left open, and also when it is plugged with wax. Explain. How does this illustrate the function of the Eustachian tube?

Experiment 18.—Put the small bottle (Fig. 15, *D*) into the receiver *R* and rarefy the air. Explain why the fountain plays. How might the apparatus be arranged so that the fountain would play into the small bottle instead of into the receiver?

Experiment 19.—Put the bottle (Fig. 15, *E*) into the receiver *R*. How may the water be made to flow from the small bottle into the receiver? How would it be possible to make the water flow from the receiver into the small bottle?

**Boyle's Law.**

Experiment 20.—By means of the Boyle's law apparatus, find the relation of volume to pressure in air.

Fig. 16 shows increase in pressure, and consequent decrease of volume of air in the closed end, *a b*, of the tube. Fig. 17 shows decrease of pressure and increase of volume. Start with the apparatus horizontal. Under how great pressure then is the air in the closed end? By what means may we increase the pressure upon it? Try increasing the pressure to twice what it originally was. How

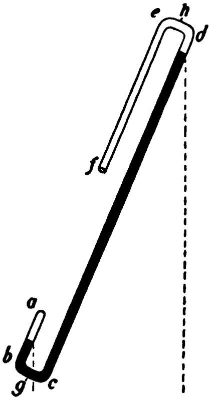

Fig. 16.

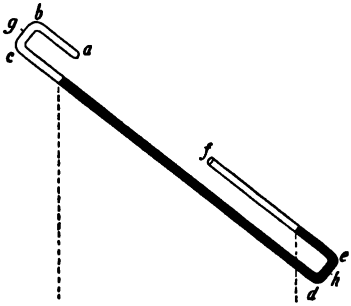

Fig. 17.

long a mercury column is pressing on the inclosed air? What has its volume become? How long a mercury column will represent $\frac{3}{2}$ of the original pressure upon it? Try increasing the pressure by this amount, and find what the volume of the air has become.

By tilting the tube in the opposite direction, increase the volume of the air to twice what it originally was. By what length of mercury column has the pressure been decreased? How does the pressure now compare with the original pressure? Try reducing the volume to $\frac{3}{4}$. What is the pressure upon it? Try increasing the volume to $\frac{3}{2}$. What is the pressure upon it? What is Boyle's law?

**Problems.**

Disregard changes due to temperature. If a cubic foot of air weighs 1.28 ounces at the sea level, what would it weigh at a height of 3 miles? If a balloon displaces 3,000 cubic feet of air, how many pounds of buoyant force would it have at the sea level? How many at a height of 3 miles? In what way would changes due to temperature affect these results?

How deep in water must a bubble of air be liberated in order that when it reaches the surface it may have twice as great a volume as when set free?

An object having a volume of 1 cubic foot weighs 2 ounces. What would it weigh in a vacuum?

# III. PRESSURE TRANSMITTED

**Principle III.**

*Pressure exerted upon a fluid (liquid or gas) inclosed in a vessel, is transmitted equally in all directions—the total pressure upon the walls of the vessel being proportional to the area.*

See how the principle is illustrated in the exercises which follow.

Experiment 21.—Using a single pressure gauge containing mercury, find how much pressure in grams per square centimeter you can exert with your lungs; connect 2 pressure gauges "in parallel" and note the pressure as indicated by each; connect 3 pressure gauges "in parallel" and note the pressure as indicated by each. (See Fig. 18.)

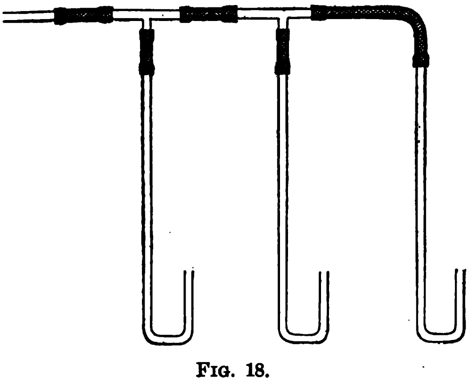

Fig. 18.

EXPERIMENT 22.—Using the apparatus represented in Fig. 19, find how many pounds (or grams) may be raised by the pressure which you may exert from your lungs.

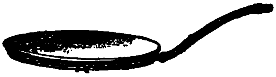

FIG. 19.

Calculate the area of the rubber cloth according to the formula ($\pi r^2$). Consider the pressure exerted by the lungs 1½ pounds per square inch. What total pressure on the rubber cloth does this represent?

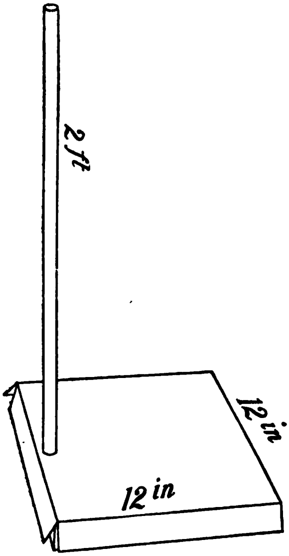

FIG. 20.

**Problem.**

Referring to Fig. 20, suppose the tube to be filled with water, what is the total force in pounds which tends to burst the cover of the box?

# IV. MISCELLANEOUS APPLICATIONS OF PRINCIPLES

Examine, operate, and explain the pieces of apparatus illustrated in the following figures.

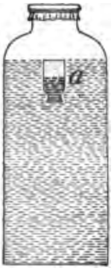

FIG. 21.

**The Cartesian Diver.**

EXERCISE 23.—The bottle *a* (Fig. 21) contains 1 cubic centimeter of air. If we exert a pressure of 5 pounds per square inch upon the rubber top, what will the volume of air in *a* become? Will it sink? Why?

**The Siphon.**

EXERCISE 24.—Explain the working of the apparatus illustrated in each of the figures 22–25. What is it necessary to do to start the action in each case? With what force are the siphons in Figs. 22, 23, and 24 operating? Why?

"Tantalus cup."

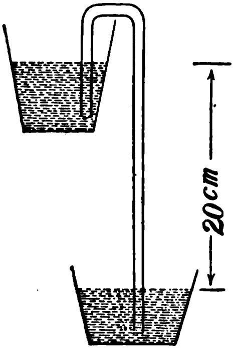

FIG. 22.

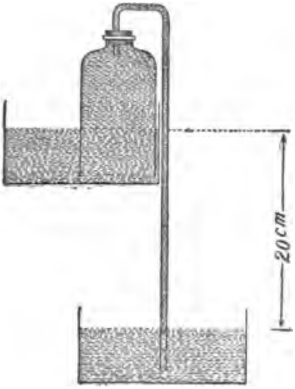

FIG. 23.

## Fountain Siphon.

Exercise 25.—Under how great pressure is the fountain (Fig. 26) operating?

Why is the rubber cloth drawn downward into the chimney?

To what must the tension of the air in the chimney be reduced in order that the water may be raised from *c* to *a*?

Sprengel's pump.

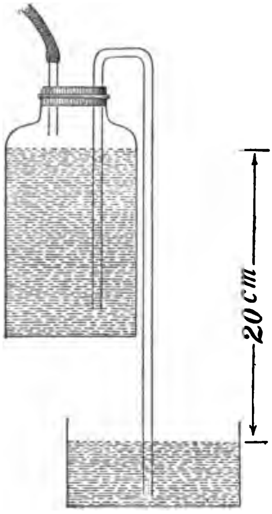

Fig. 24.

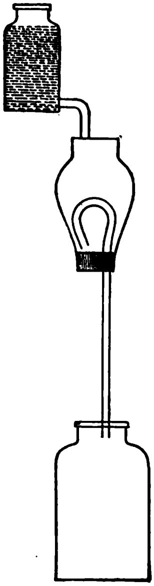

Fig. 25.

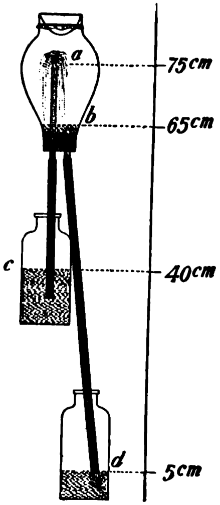

Fig. 26.

## Lifting Pump.

Exercise 26.—To what tension must the air in the cylinder of the pump (Fig. 27) be reduced in order that the water shall rise to enter it? How much must its volume be increased to produce that tension. Ignore the volume of air in the tube.

About how high may water be raised by a perfect pump of this variety? Why?

**Force Pump.**

EXERCISE 27.—Fig. 28. Why is the flow of water from the jet continuous, while in the case of Fig. 27 it was intermittent?

**Specific Gravity of Liquids.**

EXERCISE 28.—Fig. 29. By putting the tube *e* to the mouth, slightly reduce the tension of the air in the two tubes. Pinch the rubber tube, and read and record the length, *a b*, of the water column, and the length, *c d*, of the alcohol column. Compute from this the specific gravity of alcohol. Suppose the water column were 10 centimeters high. How high would a corresponding sulphuric acid column stand? What ether column would an alcohol column 12 centimeters high balance?

For table of specific gravity see page 42.

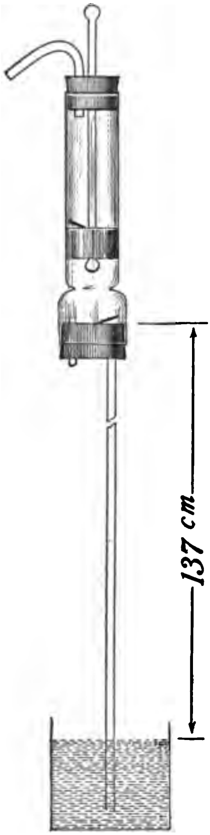

FIG. 27.

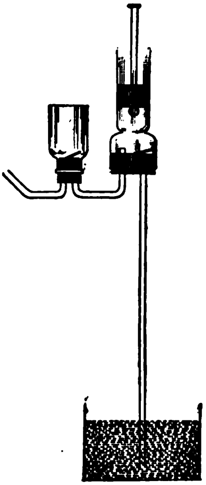

FIG. 28.

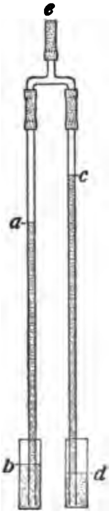

FIG. 29.

**Pressure in a Barometer Tube.**

EXERCISE 29.—Including atmospheric and water pressure, what is the pressure in grams per square centimeter at the points *a*, *b*, *c*, *d*, and *e*, Fig. 30?

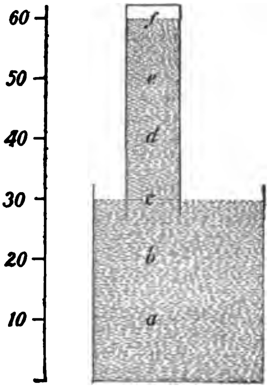

FIG. 30.

A column of water 1,033 centimeters high represents the pressure of one atmosphere. What is the tension in grams per square centimeter of the air in the upper part of the cylinder above *f*?

When the barometer stands at 30 inches, what is the pressure inside the tube at points 10, 20, and 30 inches above the zero point?

## Hero's Fountain.

EXERCISE 30.—Suppose the surface of the water in *D* and *M* (Fig. 31) to be 75 centimeters higher than that in *N*, and suppose *a* to be 15 centimeters above the surface of the water in *M*. If you place your finger on *a*, how much pressure in grams per square centimeter is exerted upon the surface of the water in *M*, and what pressure is required to stop the flow at *a*?

Would the fountain flow at the same height whether the bottle *M* were raised or lowered?

What would be the effect of raising or lowering the bottle *D*?

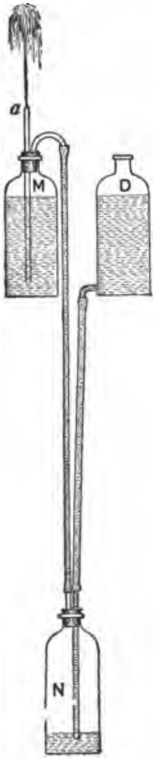

FIG. 31.

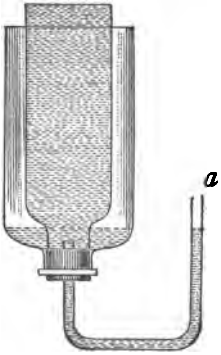

FIG. 32.

## Student's Lamp.

EXERCISE 31.—Fig. 32. Why does the water not flow out of the tube at *a* (Fig. 32)?

### Fountain Sponge Cup or Ink Well.

EXERCISE 32.—What are the advantages of a fountain sponge cup or ink well? Why does not the water in the small cup rise above *a* (Fig. 33)?

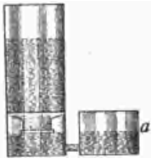

FIG. 33.

### Constant Pressure.

EXERCISE 33.—What is the purpose of the inverted bottle of water (Fig. 34)? What does the lower bottle illustrate about pressure in liquids?

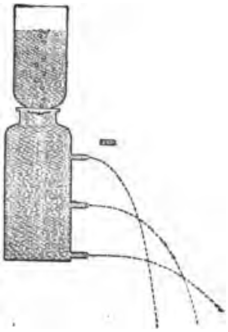

FIG. 34.

### Pressure Gauges in Series.

EXERCISE 34.—Refer to Experiment 21. Connect the three pressure gauges *in series* (Fig. 35), and predict how high mercury in each will be forced up by the pressure which you may exert with your lungs. Try it, and compare the result with your prediction. Compare this result with that obtained in Experiment 21, when they were connected *in parallel*.

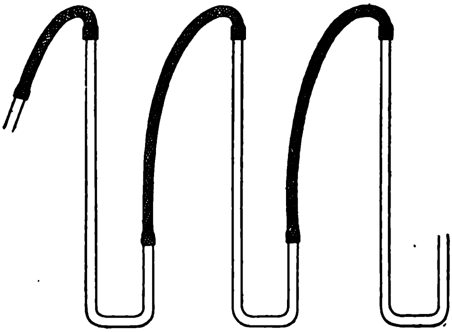

FIG. 35.

## QUESTIONS AND PROBLEMS

1. A cubic foot of ice weighing 56¼ pounds is floating in water, and $\frac{1}{10}$ of its volume rises above the surface of the water. Show how you may compute from this the weight of a cubic foot of water.

2. Granite is about 2½ times as heavy as water; how much would you be obliged to lift while holding a cubic foot of it submerged in water?

3. A mercury pressure gauge attached to a water faucet registers 30 inches. Compute the height of the water in the tank above the mercury in the pressure gauge, and the pressure it exerts in pounds per square inch and grams per square centimeter.

4. How much will a vessel weighing 50,000 pounds have to be loaded in order that it shall displace 1,000 cubic feet of water?

5. A certain spar is 20 feet long. Its cross sections are circles, and its average diameter is 1 foot. The specific gravity of the wood is .5. What is the buoyant force of the water upon the spar? How much iron (specific gravity 7.75) will be required to sink it?

6. How great will the diameter of an apparatus like that in Fig. 18 need to be in order that, with a pressure of 1½ pounds, it will be possible to lift a weight of 100 pounds?

7. What would be the buoyant force, at a height in the atmosphere where the barometer would register about 7½ inches, upon an object having a volume of 5 cubic feet?

8. In a large wide-mouthed bottle of water (Fig. 21) a small vial is inverted, having just enough air in the upper part to float it. The weight of the vial is 3.5 grams, the air which it contains is 2.5 cubic centimeters. What must be the volume of glass in it, and what is its specific gravity? The rubber cloth is air-tight over the mouth of the large bottle. If now we exert a pressure of 5 pounds per square inch upon the rubber, what will the volume of the air in the vial become? Will it sink? If so, with how much force will it press upon the bottom of the large bottle? If now we remove the pressure from the rubber cloth, and pull upward upon it with a force of 5 pounds per square inch, what will the volume of the air in the vial become? Will the vial rise above the surface of the water in the large bottle? If so, what volume will emerge?

9. If an object whose volume is 1 cubic foot weighs in air 25 grams, what would it weigh in a vacuum?

## Table of Specific Gravities, Weights, Equivalents, etc., used in the Foregoing Chapter

*These values are approximate.*

| | |
|---|---|
| Specific gravity of mercury | 13.60 |
| “ “ alcohol | .80 |
| “ “ sulphuric acid | 1.80 |
| “ “ ether | .74 |

| | |
|---|---|
| Weight of 1 cubic inch of mercury | .50 lb. |
| “ 1 “ centimeter of mercury | 13.60 gms. |
| “ 1 “ “ water | 1.00 gm. |
| “ 1 “ foot of water | 62.50 lbs. |
| “ 1 liter of water | 1,000.00 gms. |
| “ 1 “ air | 1.29 “ |
| “ 1 cubic foot of air | 1.28 oz. |

1 centimeter = .3937 in.
1 inch = 2.54 cm.
1 decimeter = 10 cm.
1 meter = 10 dm.
1 meter = 100 cm.
1 meter = 39.37 in.

Area of circle = $\pi r^2$ ($\pi = 3.1416$).
Volume of cylinder = area of cross section × length.
Volume of sphere = $\frac{1}{6}\pi D^3$.

# HEAT

I. How Heat is produced.
  A. *Heat produced by Friction.*
    Experiments 1, 2, 3, and 4.
  B. *Heat produced by Pressure.*
    Experiments 5, 6, and 7. Figs. 1, 2, and 3.
  C. *Heat produced by Chemical Action.*
    Experiment 8.
II. Some Effects of Heat.
  *Expansion of Gases.*
    Experiments 9, 10, and 11. Figs. 4 and 5.
  *Change of State.*
    Experiments 12 and 13. Fig. 7.
  *Expansion of Liquids—Mercury Thermometers.*
    Experiments 14, 15, 16, and 17. Figs. 8 and 9.
  *Expansion of Solids.*
    Experiments 18, and 19. Fig. 10.
  *Evaporation—Distillation—Dew-point.*
    Experiments 20, 21, 22, 23, 24, 25, 26, 27, and 28. Figs. 11 and 12.
III. How Heat is transferred.
  A. *Heat transferred by Conduction.*
    Experiments 29, 30, 31, 32, 33, 34, and 35. Fig. 13.
  B. *Heat transferred by Convection.*
    Experiments 36, 37, and 38. Figs. 14, 15, 16, 17, and 18.
  C. *Heat transferred by Radiation.*
    Experiments 39, 40, 41, and 42. Figs. 19, 20, and 21.
IV. Specific Heat and Calorimetry.
  Experiment 43.
V. Latent Heat.
  A. *Heat disappears when Solids liquefy.*
    Experiments 44 and 45.
  B. *Heat disappears when Liquids vaporize.*
    Experiment 46.
  C. *Heat reappears when Vapors liquefy.*
    Experiment 47. Fig. 22.
  D. *Heat reappears when Liquids solidify.*
    Experiment 48.
  Questions and Tables.

# I. HOW HEAT IS PRODUCED

## A. **Heat produced by Friction.**

EXPERIMENT 1.—Fasten a strip of tin to a block of wood and grind the tin upon stone or wood until it is hot enough to light a small piece of phosphorus upon a plate.

Hot axle on cars; on wagons. Machinery warms up while running. What is done to obviate this? Saw gets hot while sawing wood. Grease used to reduce friction, and thereby diminish heat. The charring of a stick of wood by rubbing it against a rapidly moving wheel.

EXPERIMENT 2.—Produce sparks by striking a pebble a glancing blow against a rasp.

Sparks produced by emery wheel. Horse's shoe striking the pavement. Scissors grinder. Car brakes.

EXPERIMENT 3.—Try to light a *friction* match by drawing it across first a very smooth surface (a pane of window glass), and second a rather rough surface (a pane of ground glass). Why does it light more easily upon one surface than the other?

EXPERIMENT 4.—Bend a strip of tin back and forth rapidly until it gets hot. Why?

Rocks fused by flexing of the earth's crust. Is animal heat due in any degree to friction?

### B. Heat produced by Pressure.

EXPERIMENT 5.—With a pump condense air in a bottle containing a thermometer to indicate changes of temperature (Fig. 1). Exhaust air from the bottle, and notice whether the thermometer falls.

EXPERIMENT 6.—With a pair of forceps pinch the rubber delivery tube (Fig. 2) to check the flow of steam. Note the effect upon the temperature. Do not force the temperature above 105° C.

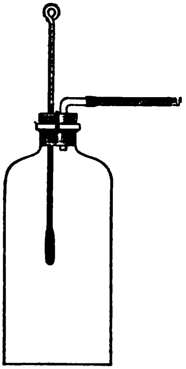

FIG. 1.

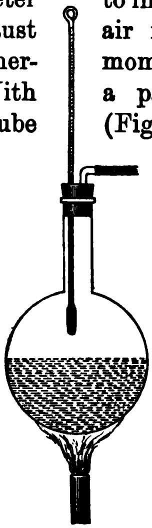

FIG. 2.

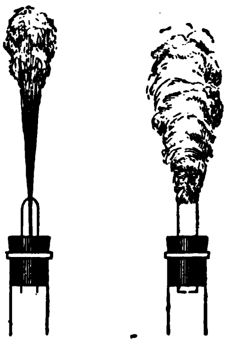

FIG. 3.

EXPERIMENT 7.—Notice difference in temperature in the steam which comes from two flasks (Fig. 3). The delivery tube of one is nearly closed and the steam rushes out under considerable pressure, while from the other it flows slowly. Try the temperature, both with the hand and with the thermometer.

Steam jet from locomotive. Fall of temperature when a "soda-water" bottle is uncorked. Manufacture of ice. Internal heat of the earth. Heat of the sun.

### C. Heat produced by Chemical Action.

EXPERIMENT 8.—Hold in the palm of one hand a small dish containing a piece of quicklime as large as a hen's egg. Add cold water, and note the heat which will be produced. Give plenty of time, and note how the heat increases. Use the thermometer, and see if the temperature rises as high as the boiling point of water (100° C).

Compost heaps get very warm, by reason of the chemical decomposition that is going on in them. Piles of green grass, new grain, new hay, new flour, cotton with seed in it, or oily cotton waste all produce heat for the same reason. Animal heat.

## II. SOME EFFECTS OF HEAT

### Expansion of Gases.

*Heat acts like a force within a mass to drive its particles farther apart. It expands gases, liquids, and solids.*

EXPERIMENT 9.—Heat a flask filled with air, having a rubber cloth tied air-tight over its neck (Fig. 4). Notice that when the flask is heated the rubber cloth bulges up. Allow the flask to cool until you can bear your hand on it, then pour cold water over it. Why is the rubber cloth now pushed downward into the neck of the flask?

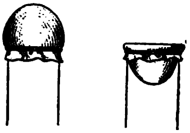

FIG. 4.

**Experiment** 10.—Prepare some hot soapsuds. Now roll a tumbler in the suds. Take it out and shake once or twice, so as to entrap in the tumbler some cold air. Then bring the tumbler, mouth downward, on a plate containing enough soapy water to seal the mouth of the tumbler. Why do bubbles first appear on the outside of the tumbler? Explain their final appearance on the inside.

This phenomenon frequently occurs in the kitchen when tumblers are taken from the suds.

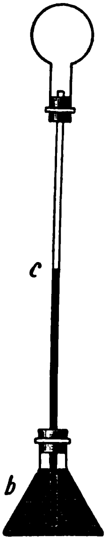

Fig. 5.

**Experiment** 11.—Hold the bulb of the air thermometer (Fig. 5) in the palm of your hand for a short time, and note the height of the liquid in the tube. Rub the palms of your hands together vigorously, and again close one of them around the thermometer bulb. Note the height of the liquid in the tube. The tube *c* goes through an ordinary cork and dips into some colored liquid in the bottle *b*. Why does the liquid rise in *c* when the temperature falls, and fall in the tube when the temperature is raised?

Why is an air thermometer so sensitive?

**Hot-air engines.**

## Change of State.

*Heat changes solids to liquids and liquids to gases by expansion.*

EXPERIMENT 12.—Melt some paraffin in a small cup or jar over boiling water until the cup is even full of the liquid paraffin. Allow it to cool, and notice that it contracts very perceptibly on cooling. Illustrate by a sketch, and designate it Fig. 6.

Why can not paraffin and wax candles be cast in a mold?

EXPERIMENT 13.—Fill a test-tube about one third full of water. Plug the tube by inserting halfway into it a rubber stopper that can be with difficulty forced into it. Heat the water in the test-tube until the rubber stopper is forced out (Fig. 7).

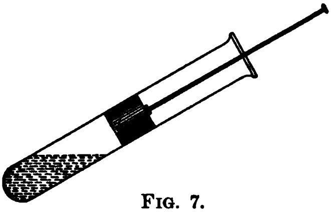

FIG. 7.

Steam engines.

## Expansion of Liquids—Mercury Thermometers.

EXPERIMENT 14.—Repeat Experiment 11 with a mercury thermometer. Find what is the temperature of your blood upon either Fahrenheit or centigrade scale, and translate it into the corresponding temperature upon the other scale. Do the same with the temperature of the air in the room, the water from the faucet, or other specimens of water which may be furnished you.

On the centigrade scale the freezing point is 0° and the boiling point 100°. On the Fahrenheit scale the freezing point is 32° and the boiling point 212°. Therefore there are 100° between the freezing and boiling points on the centigrade scale, and 180° between the freezing and boiling points on the Fahrenheit. Nine Fahrenheit degrees are equal to five centigrade degrees; or, in other words, a centigrade degree is $\frac{9}{5}$ of a Fahrenheit degree, and a Fahrenheit degree is $\frac{5}{9}$ of a centigrade degree.

**Experiment 15.**—Note the size of bore of the tube of a broken thermometer. What is the advantage of having the tube so small and the bulb so large? What advantage in thin walls for the bulb?

**Experiment 16.**—Determine the 0 point on your centigrade thermometer (or 32° on a Fahrenheit thermometer); also determine the 100° point (or 212° point). Use apparatus represented in Figs. 8 and 9 for this purpose.

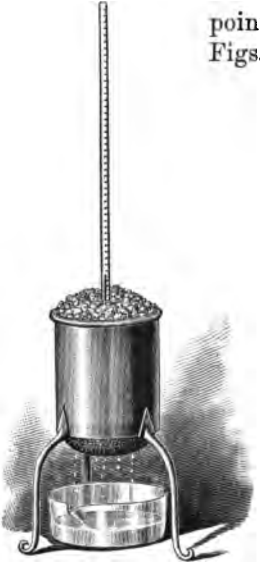

Fig. 8.

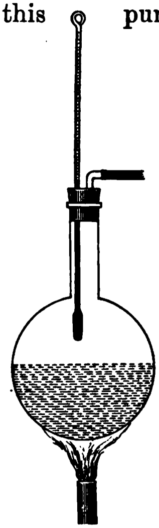

Fig. 9.

*Contraction by cold is in the following case more than balanced by expansion of crystallization.*

**Experiment 17.**—Fill a one-ounce narrow-mouthed bottle with water, cork it, and surround it with a mixture of ice and salt in a tumbler. In fifteen or twenty minutes the water should have frozen and broken the small bottle.

Why does ice float upon water?

The above experiment illustrates the expansion of crystallization of various substances—for example, type metal. What kind of substances may be cast in molds?

## Expansion of Solids.

EXPERIMENT 18.—Illustrate the expansion of solids by heating a fine wire stretched between two supports.

EXPERIMENT 19.—Heat two strips of metal, *a* and *b* (Fig. 10), as uniformly as possible by holding them in a flame. (*a* is a strip of brass, and *b* a strip of iron.) Notice that the metals expand unequally. Which expands the more?

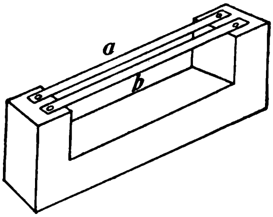

FIG. 10.

Examine a metal thermometer, and explain the principle upon which it is constructed.

## Evaporation—Distillation—Dew-point.

EXPERIMENT 20.—Warm a plate and put it by the side of a cold plate. Put a drop of water upon each, and note the time of evaporation in both cases.

Dishes taken from hot rinsing water dry more quickly than when taken from cold water. Clothes dry more rapidly when wrung out of hot water than cold water; when hung near a hot stove than in a cold room. The body dries faster when coming from a hot bath than from a cold one.

Heat acts like a force within a mass to drive its particles farther apart, and thus expands liquids into vapors. Vapors condense to liquids again on cooling. By this process of distillation we are able to recover salts from solutions.

EXPERIMENT 21.—Make a solution of salt in water (about half a teaspoonful in an ounce of water) and distill a portion of it (Fig. 11). Taste the solution and the distillate. Did the distillate pass through an invisible state in the process of distillation? Pour the solution into an evaporating dish, and evaporate to dryness over a water bath. How does the amount of salt left compare with that taken for the experiment?

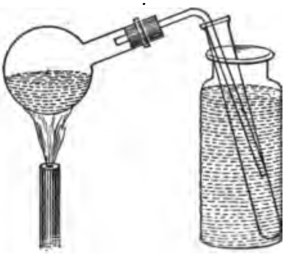

FIG. 11.

The process of distillation is illustrated by what goes on in the laundry. The water evaporates from the boiler, and is condensed to drops upon the window pane. This process goes on in a large way in Nature—fog, mist, clouds, rain, and dew.

EXPERIMENT 22.—In a bright metal cup put water, and add slowly small pieces of ice. Stir with a thermometer, and notice the temperature of the water at the moment dew begins to appear upon the outside of the cup. Slowly add water, stir continually, and notice the temperature of the water at the moment the dew disappears. If the two readings agree closely (within 2°), average them. This average temperature is the "dew-point."

Drops of water upon an ice pitcher. "Seeing the breath" in a cold atmosphere. Frost on the window pane. The evaporation from ocean and lakes which have no outlets must be equal to all the water which is supplied to them by rivers and rain.

EXPERIMENT 23.—Arrange the following according to the facility with which they evaporate at the temperature of the room: Ether, alcohol, water, gasoline, benzine.

EXPERIMENT 24.—Cause mercury to evaporate by heating it in a test-tube. Notice the drops of mercury that condense on the cooler portions of the tube.

*Some substances appear to pass directly from the solid to the gaseous state without passing through the liquid state.*

Experiment 25.—Heat a test-tube or flask for a few moments, and after taking it from the flame drop into it a crystal of iodine. Examine also a bottle in which iodine has stood, and notice evidences of evaporation at the ordinary temperature.

The evaporation of camphor. The evaporation of ice on cold, *windy* days. Clothes "freezing dry."

## Relation of Pressure to Evaporation.

Experiment 26. — Breathe into two 8-ounce flasks so as to cloud them with moisture. Pump air from one of the flasks, and compare the evidences of evaporation in the two flasks.

Experiment 27.—Use apparatus represented in Fig. 12. Heat the water nearly to the boiling point, remove the lamp, and connect the exhaust nipple of the pump. Take a few strokes, and note the effect upon the rate of evaporation; also note the temperature as indicated by the thermometer. Exhaust still further, and see if you can make water boil at a temperature, say, of 75° C.

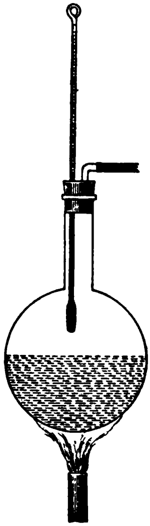

Fig. 12.

Refer to Experiment 6. Temperature of water in engine boilers. Extraction of gelatin from bones. Papin's Digester.

Boiling point on mountain tops. Vacuum pans in sugar refineries, milk condensers, etc.

### Effect of Currents of Air upon Evaporation.

EXPERIMENT 28.—Evaporate drops of water from two plates. Blow across one of them.

Clothes dry more quickly on windy than on still days. "Muggy days." Humidity.

## III. HOW HEAT IS TRANSFERRED

### A. Heat transferred by Conduction—Conductors Good and Bad.

EXPERIMENT 29.—Heat at their conjunction an iron and a copper wire which have been linked together. Pass the hand along each wire toward the flame to determine which is the better conductor of heat. Burn a match at one end; why is there no heat perceptible at the other end? Melt a short piece of glass at one end while holding the other end in the hand.

EXPERIMENT 30.—Heat two iron wires in the flame—one a very thin wire taken from the wire gauze to be used in the next exercise, and the other a thick one. Why does the small wire quickly reach the melting point of iron, while the larger one is scarcely heated red hot?

EXPERIMENT 31.—Hold in a flame a piece of thin wire gauze made of the same wire as above, with meshes about forty to the inch. Why is it not easily heated red hot? Why does not the flame pass up through the gauze? By means of a lighted match determine whether unburned gas is passing up through the gauze.

EXPERIMENT 32.—Extinguish the flame of the Bunsen burner, lay the wire gauze over the mouth of the lamp, turn on the gas, and light it above the gauze and slowly raise the latter. Why does not the flame extend through the gauze to the mouth of the lamp?

**Experiment** 33.—Use apparatus to illustrate the Miners' Safety Lamp as represented in Fig. 13. Light the lamp and pass it into a bottle of illuminating gas. Try bringing an unprotected flame to the bottle filled with illuminating gas. Explain these phenomena in the light of Experiments 31 and 32.

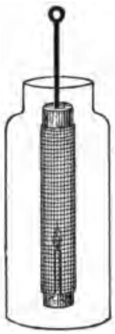

Fig. 13.

**Experiment** 34.—Float an evaporating dish upon a vessel containing a small amount of water (a beaker is convenient). Immerse a small thermometer inverted in the water, with the bulb very near to but not touching the evaporating dish. Pour alcohol into the evaporating dish and light it. Notice that the water boils where it comes in contact with the sides of the dish. How is the thermometer affected? Try the same experiment with the thermometer bulb downward. In each case, after taking the thermometer reading, stir the water and read again. Is water a good or poor conductor of heat? Does the summer's sun heat bodies of water to any great depth?

**Experiment** 35.—Put a small thermometer into a test-tube, and heat the upper end of the tube in the flame. Does the air in the tube conduct heat to the thermometer? Remove the flame and tip the tube so that its mouth shall be slightly below the other end. Note the change in the thermometer.

Conducting and non-conducting materials used for clothing; used for handles of stove utensils; wrappings for hot stones, for furnaces, for steam pipes. How are the crops protected by snow in winter? Double windows used in houses in winter time.

## B. Heat transferred by Convection.

Experiment 36.—Cause a current of air to pass through a pasteboard box by means of two Argand lamp chimneys and a lighted candle, as in Fig. 14. To detect the course of the current, bring a smoking lamplighter to the top of the chimney in which the candle is burning. Then bring it over the other chimney, and explain why smoke goes down that chimney and up the other. Also cause a current of air to pass through a common lamp chimney by using a cardboard partition and a lighted candle, as in Fig. 15.

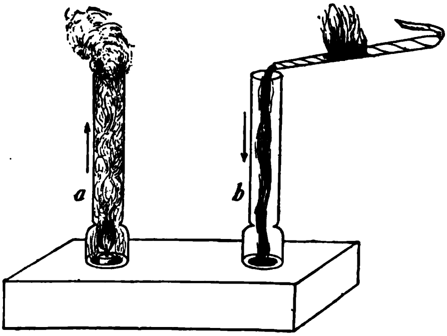

Fig. 14.

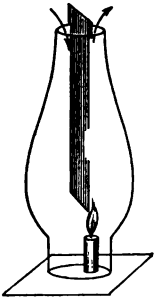

Fig. 15.

Experiment 37.—Place a small flame under one side of a beaker with a metal partition in it (Fig. 16). Drop in flakes of something to show convection currents in water.

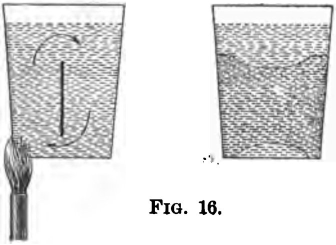

Fig. 16.

Experiment 38.—Illustrate how currents of water move into the hot-water tank by using apparatus like that in Figs. 17 and 18, where *A* represents the boiler, *B* the pipes, and the burner the kitchen range.

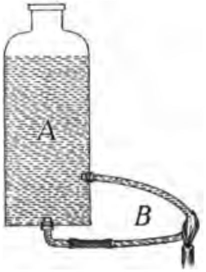

Fig. 17.

Hot-water pipes in the house. Winds. Land and sea breezes. Ocean currents. Ventilation.

## C. Heat transferred by Radiation.

Experiment 39.—Cause the radiometer to move by the radiation from your hands; by the radiation from a cup of hot water.

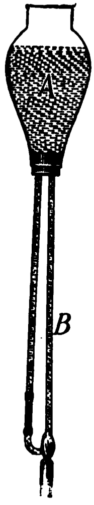

Fig. 18.

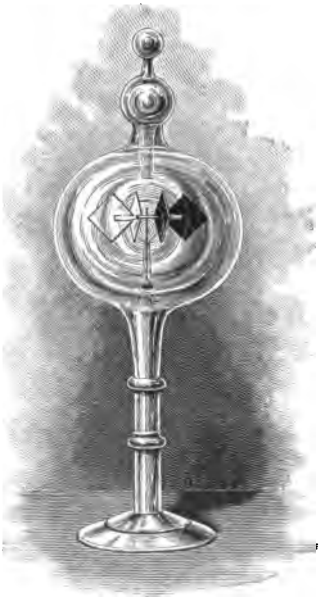

Fig. 19.

Experiment 40.—Smoke the bulb of one air thermometer, and cover the bulb of another with tin foil. Hold a basin of hot water over them (Fig. 20). Which absorbs the most heat? Remove the tin basin and watch the movement of the liquid in each. Which radiates the most heat?

Experiment 41.—In Fig. 21 *a* represents a disk of wood well painted. A hole is bored through the center of this disk so that it will fit tightly upon the tube of a Bunsen burner. One sector of this disk (*b*) is covered with tin foil, another sector (*c*) is covered with thin sheet asbestos, a third sector (*d*) is left unprotected. Light the burner and support over the flame a basin of water. After subjecting it to this radiation for half an hour or so, remove the coverings from the disk, and note which sector appears to have been heated most.

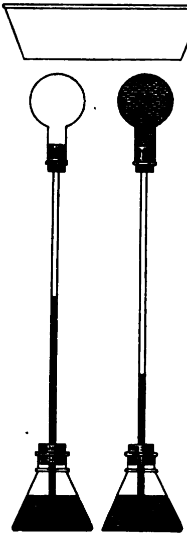

Fig. 20.

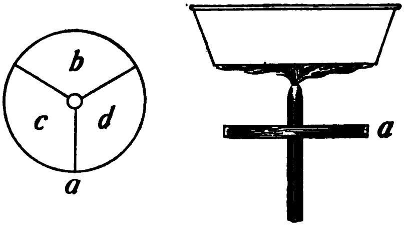

Fig. 21.

Experiment 42.—Remove the flasks from the air thermometers (Fig. 20). Fill them with hot water and note their relative rate of cooling.

How do we get heat from an open fireplace? Would we be able to receive heat from the fire if there were no atmosphere or matter of any kind in which conduction or convection could occur? How do we get heat from the sun? The hotbed. The greenhouse. Why do dew and frost collect more upon some things than upon others? How does snow protect crops?

# IV. SPECIFIC HEAT AND CALORIMETRY

EXPERIMENT 43.—Have 200 cubic centimeters of water at the temperature of the room in each of two vessels (calorimeters). (Bright metal cups will serve the purpose.) Note the temperature. In a third vessel have 200 cubic centimeters of water, with a piece of lead in it weighing 200 grams. Have a thread attached to the lead, so that you may transfer it from one vessel to another. Cover this third vessel to prevent loss of water by evaporation, and heat it nearly to the boiling point of water. Remove the lamp, take the temperature of the water (and lead?), and quickly transfer the lead to one of the aforementioned vessels of water and into the other pour the hot water. Stir the hot and cold water together, and move the lead about for a few moments to make the temperature in each uniform. Now note the resulting temperature in each. Calculate from the above results the specific heat of lead. What are some of the sources of error in the experiment? Try the experiment over again, eliminating as many of the sources of error as possible. What is the difference between temperature and quantity of heat?

# V. LATENT HEAT

## A. **Heat disappears when Solids liquefy.**

Experiment 44.—Take the temperature of some water. Wipe the thermometer dry and take the temperature of some fine salt. Mix salt in the water, and take the resulting temperature.

Experiment 45.—Take the temperature of some shaved ice. Mix salt with the ice, and take resulting temperature. Does the ice liquefy faster when mixed with salt than otherwise? While it is changing from solid to liquid, how is its temperature changing? Why is salt put upon icy pavements?

Freezing mixtures.

## B. **Heat disappears when Liquids vaporize.**

Experiment 46.—Take the temperature of ether in the bottle. Put a little in a watch crystal or an evaporating dish, and note its temperature while it is evaporating. Blow across it. Why? Note the temperature. Put a drop of water upon a block of wood, and set the watch crystal containing ether in the water on the block. Blow across the ether until the drop of water freezes.

Ice machines. The water bath. The double boiler. Animal heat reduced by perspiration. Sprinkling with water for the purpose of cooling. "Muggy days." Humidity. Why is it difficult to cook on a mountain top? Freezing produced by reducing the pressure.

## C. Heat reappears when Vapors liquefy.

EXPERIMENT 47.—Take 200 grams of water in a flask (Fig. 22, *a*). Note its temperature. Pass steam into it from another flask (*b*) until its temperature rises, say, 50°. Weigh to find how much water has been added by condensation of steam. How many units of heat have been added to the flask? How many are due to the liquefying of the steam? How many units of heat for each unit of steam liquefied? (The stopper in *a* must have holes to permit of ready expansion.)

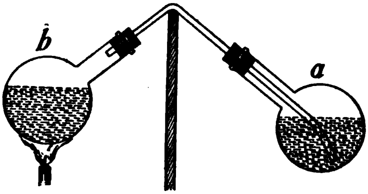

FIG. 22.

Steam heating of buildings. Temperature in the center of a rain storm.

## D. Heat reappears when Liquids solidify.

EXPERIMENT 48.—Put 27 grams of sodium sulphate into 50 grams of water in a flask, heat to 34°, and stir until all is dissolved. Allow it to stand very quietly, so as to cool without depositing crystals. When it has cooled to the temperature of the room, put a thermometer into the liquid and stir. Note the rise in temperature as the sodium sulphate deposits.

Temperature in the center of a snowstorm. Tubs of water put in a cellar to keep vegetables from freezing. Large bodies of water in freezing modify the climate.

## QUESTIONS

1. Describe some experiments illustrating changes of temperature produced by chemical action, by friction, and by dissolving a solid in a liquid.

2. Explain how it is that snow protects vegetation in winter. Will wrapping a thermometer in wool make it warmer? Why do woolen blankets keep the body warm?

3. How do large bodies of water modify the climate about them? Explain.

4. Why is it warmer in the center of a storm than in its outskirts?

5. Why does the skin feel cold when moistened with alcohol? Why does it feel cooler after being moistened with warm water than with cold water?

6. Why does a mixture of ice and salt freeze water?

7. Explain the use of double doors and windows in winter.

8. Why is it possible to hold one's hand in the steam coming from a locomotive boiler, when the temperature of the water inside the boiler may be far above 212° F.? How is it possible to raise water above 212° F.?

9. Explain how it is possible for fish to live all winter in the lakes of cold regions, where the thermometer falls below zero.

10. A liter of hydrogen gas weighs, at 0° and 76 centimeters, about .089 grams. Calculating from these data, in a certain quantitative experiment, one expected to obtain 200 cubic centimeters of hydrogen. How many cubic centimeters might actually have been collected when the thermometer stood at 20° C. and the barometer at 75 centimeters?

11. How many grams of lead will be needed to give off as much heat in cooling through 10° as will be given off by 100 grams of water in cooling through 10°?

12. If equal weights of water at 20° and mercury at 70° were poured together, what would be the resulting temperature?

13. Through how many degrees could 100 grams of water be heated by the amount of heat given off by the melting of 10 grams of ice? How many heat units would it take to change into steam the water formed by the melting of the ice?

## TABLES FOR REFERENCE

To translate one thermometer scale into another.

$$C = \frac{5}{9}(F. - 32).$$
$$F = \frac{9}{5}C. + 32.$$

### *Boiling Points*

| | |
|---|---|
| Ether | 37° |
| Alcohol | 70° |
| Water | 100° |
| Mercury | 358° |

### *Specific Heat*

| | |
|---|---|
| Copper | .095 |
| Iron | .114 |
| Lead | .031 |
| Mercury | .033 |

### *Latent Heat of Vaporization*

| | |
|---|---|
| Ether | 90 |
| Alcohol | 202 |
| Water | 537 |

### *Latent Heat of Fusion*

| | |
|---|---|
| Ice | 80 |

### *Coefficients of Expansion (Linear)*

| | |
|---|---|
| Copper | .000017 |
| Iron (cast) | .0000112 |
| Iron (wrought) | .000012 |

### *Coefficient of Expansion (Cubical)*

| | |
|---|---|
| Gases | .00366 |

# MAGNETISM AND ELECTRICITY

A. MAGNETS.
  I. *Natural and Artificial Magnets.*
    Experiments 1, 2, 3, and 4.
  II. *Induced Magnetism.*
    Experiments 5, 6, and 7. Fig. 1.
  III. *The Molecular Theory of Magnets.*
    Experiments 8, 9, 10, and 11.
B. STATIC ELECTRICITY.
  I. *Two Kinds of Electrification.*
    Experiments 12, 13, 14, and 15. Fig. 2.
  II. *Conduction.*
    Experiment 16. Fig. 3.
  III. *Induction.*
    Experiments 17, 18, and 19. Fig. 4.
  IV. *Electrical Distribution.*
    Experiments 20 and 21.
  V. *Application of Principles.*
    Experiments 22, 23, and 24.
C. ELECTRIC CURRENTS.
  I. *The Battery Cell.*
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    A. Chemical Effects.
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      Experiments 35, 36, 37, 38, 39, 40, and 41.
  IV. *Electrical Measurements.*
    Experiments 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, and 53.
  V. *Induction.*
    Experiments 54, 55, and 56.
  Questions. Tables.

# MAGNETISM AND ELECTRICITY

## A. MAGNETS

### I. **Natural and Artificial Magnets.**

EXPERIMENT 1.—Dip a piece of magnetite into iron filings. Find whether the filings cling to opposite parts.

EXPERIMENT 2.—Suspend the piece of magnetite. Note whether one part of it is inclined to point north.

EXPERIMENT 3.—Find a spot on the magnetite where iron filings cling most abundantly and lay this spot upon one end of a *steel* needle and draw it to the other end of the needle. Repeat this several times, always in the same direction. By means of the iron filings find whether the needle has become a magnet. Try the same experiment, using a piece of soft iron wire in place of the needle.

EXPERIMENT 4.—Having magnetized a needle, find out whether this needle will magnetize other needles.

### II. **Induced Magnetism.**

EXPERIMENT 5.—While holding one end of a bar magnet near one end of a short rod of iron, test the power of the latter to lift iron filings. Remove the magnet. How is the iron affected?

EXPERIMENT 6.—Bring the horseshoe magnet near to a suspended rod of soft iron so that a pole of the magnet is underneath each end of the iron rod. Now by means of a bar magnet test the iron rod for polarity.

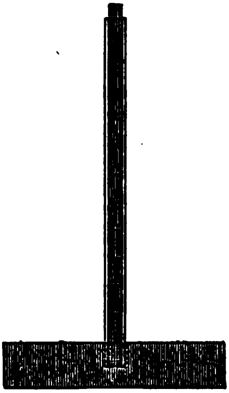

FIG. 1.

EXPERIMENT 7.—Support in a vertical position a glass tube about three inches long and one eighth of an inch internal diameter by fitting one end of it into a cork large enough to serve as a base. Fill the tube with pieces of soft iron wire of uniform size (say a quarter of an inch long). Find how many bits of iron each pole of a bar magnet will lift, and try the power of the magnet at various points between the poles. Lay a second bar magnet upon the first with like poles together and repeat the experiment. Repeat the experiment, having unlike poles together. Place one pole of a magnet upon the upper end of the glass tube and place the opposite pole of another magnet against the side of the tube an inch or two below the upper end. Try, now, the power of the upper magnet to lift bits of iron. Reverse the poles of the lower magnet and try again.

## III. The Molecular Theory of Magnets.

EXPERIMENT 8.—Magnetize a sewing needle, present it to iron filings. Heat it red hot; now again test its magnetism by means of iron filings, or test it by means of the apparatus described in Experiment 7.

EXPERIMENT 9.—Magnetize a knitting needle, test its magnetism by the apparatus described in Experiment 7. Drop it upon the floor several times; now test its magnetism again.

EXPERIMENT 10.—Magnetize a sewing needle; test it for poles and a neutral point. Break it at the neutral point; test for new poles and neutral point. Break again at neutral point and test for new poles.

EXPERIMENT 11.—Place two bar magnets about an inch apart with like poles adjoining. Cover them with a piece of glass. Sprinkle fine iron filings thinly over the glass, tapping the glass occasionally to assist the filings in arranging themselves. Draw a sketch to illustrate the arrangement of the filings.

Repeat the experiment, placing *unlike* poles of the magnet adjoining each other. Repeat the experiment, using a horseshoe magnet instead of a bar magnet.

## B. STATIC ELECTRICITY

### I. Two Kinds of Electrification.

EXPERIMENT 12.—Make a stick of sealing wax slowly approach and touch a pith ball suspended upon a silk thread (Fig. 2). Now do the same after having rubbed the sealing wax with flannel. By sliding the silk thread make this pith ball slowly approach and touch another pith ball suspended in the same manner. Make the stick of sealing wax slowly approach and touch, if it will, each of the pith balls again. Be careful not to touch either of the pith balls with your hand during the exercise.

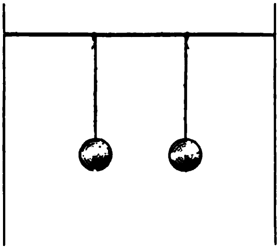

FIG. 2.

EXPERIMENT 13.—(Before beginning this exercise touch each pith ball with your hand to discharge any electricity which may have been left in it from the last exercise.) Repeat the foregoing exercise, using a glass tube and silk in place of the stick of sealing wax and flannel.

Experiment 14.—Discharge with the hand if necessary the two pith balls. Suspend them several inches apart. Electrify one by means of the sealing wax and the other by means of the glass tube. Now make the glass tube approach *but not touch* the first pith ball, and the stick of sealing wax approach *but not touch* the second pith ball. Also make the pith balls approach each other by sliding the silk threads.

Experiment 15.—Charge one pith ball positively and the other negatively. Rub the glass tube with a silk cap to which is attached a silk thread by means of which the cap may be drawn off the tube. Make the cap approach *but not touch* each pith ball in turn. Is the silk cap electrified? How? What is the proof?

Rub the stick of sealing wax with a flannel cap and by means of a silk thread attached to it make it approach *but not touch* each pith ball in turn. Is the flannel cap electrified? How? What is the proof?

## II. **Conduction.**

Experiment 16.—Electrify a stick of sealing wax and touch it to the silk thread, *a b* (Fig. 3). Do the pith balls at either *e* or *f* separate? Slide the stick of sealing wax over to the copper wire, *b c*. Do the pith balls at either *e* or *f* separate now? (Those at *f* are suspended by copper wires and those at *e* are suspended by silk threads.)

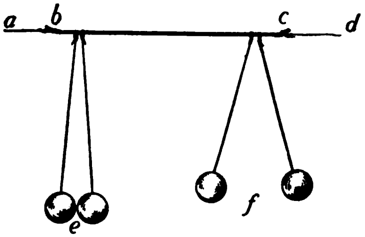

Fig. 3.

Moisten the silk threads which suspend the pith balls at *e*. Try now to conduct electricity to them by touching the copper wire, *b c*, with the electrified stick of sealing wax.

## III. Induction.—The Influence of Electrified Bodies upon Neighboring Objects.

Experiment 17.—Bring an electrified stick of sealing wax underneath a pith ball, *e* (Fig. 4), suspended by a copper wire. Make the sealing wax approach very near to the pith ball, but do not allow it to touch. While holding the sealing wax near to *e*, lift the pith ball *f*, which is also suspended by a copper wire, off from the copper wire, *b c*, and hang it upon the silk thread, *c d*. A loose piece of silk thread, *g*, is provided, so that this may be done without touching the copper with the fingers. Test now each ball with both glass and sealing wax to determine whether it is positively or negatively electrified.

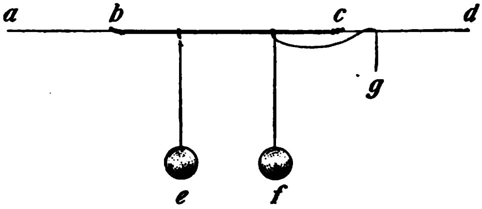

Fig. 4.

Experiment 18.—Hold an electrified stick of sealing wax near to but not touching a pith ball suspended by a silk thread. Touch the pith ball with the finger while it is near the sealing wax. Test now the pith ball with both glass and sealing wax to determine whether it is positively or negatively electrified.

Experiment 19.—Can you, by means of an electrified glass tube, charge a pith ball suspended upon a silk thread either positively or negatively at pleasure? Try it.

### IV. Electrical Distribution.

EXPERIMENT 20.—Hold a glass tube by the hand placed midway between the two ends, and rub one end with silk. By means of a positively electrified pith ball determine whether the other end of the glass tube is also electrified. Explain.

EXPERIMENT 21.—Electrify, by touching it several times with an electrified glass tube, or the electrophorus, a small tin cup insulated upon a glass beaker. Test both the inner and outer surface of the cup by means of a positively electrified pith ball. Compare also the intensity of the charge in the handle with that upon the outer surface of the cup.

### V. Application of Principles.

EXPERIMENT 22.—Use an electrophorus to charge a Leyden jar so that its outer coat shall be first positively charged, then negatively charged.

EXPERIMENT 23.—Pass ten or twenty sparks into a Leyden jar from an electrophorus and then discharge it through your body.

EXPERIMENT 24.—Light the gas by means of a spark from a Leyden jar.

## C. ELECTRIC CURRENTS

### I. The Battery Cell.

EXPERIMENT 25.—Dip a strip of zinc into dilute sulphuric acid (1 volume of acid to 20 volumes of water) in a tumbler. Note the bubbles of hydrogen which form upon its surface. Dip a strip of copper into the acid, and note that bubbles do *not* form upon its surface. Allow the ends of the strips which extend above the liquid to touch each other. Note that bubbles of gas now form also upon the strip of copper. Amalgamate the zinc with mercury.

Note that few, if any, hydrogen bubbles are now produced upon the surface of the zinc, but when the upper ends of the zinc and copper touch, hydrogen bubbles appear upon the latter. Drop sodium bichromate into the solution until hydrogen bubbles disappear from the copper strip. If the strips are allowed to remain in the acid with the upper ends connected, it will be found that the zinc wastes away while the copper remains undiminished. What are the essentials of a battery cell?

EXPERIMENT 26.—Examine a Samson or other cell and explain how it fulfills the essential requirements of a battery cell.

## II. To detect the Presence of an Electric Current and its Direction.

EXPERIMENT 27.—Place a cell so that the carbon pole is due north of the zinc pole. Connect them by a short piece of copper wire, which will lie in the magnetic meridian. Hold a compass needle over this wire, and note in which direction its north-seeking pole is deflected. Hold the compass needle underneath the wire, and note in which direction the north-seeking pole is deflected. Do not leave the copper wire in circuit longer than is necessary.

EXPERIMENT 28.—From the data obtained in the previous experiment, determine by means of a compass needle in what direction an electric current is passing through a given wire.

## III. Some Effects of Electric Currents.

### A. *Chemical Effects*

EXPERIMENT 29.—Attach carbon terminals to the wire connected with a battery. Dip them into a solution of copper sulphate, not allowing them to touch each other. Notice what occurs on each electrode.

EXPERIMENT 30.—Pass an electric current through water in the apparatus provided for the electrolysis of water. Continue the operation until one of the tubes is full of gas. Note at this point how much gas the other tube contains. Test these gases for hydrogen and oxygen.

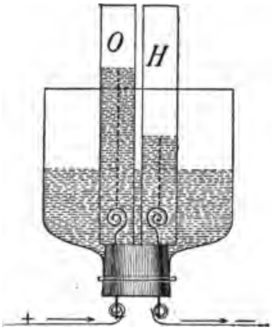

FIG. 5.—Electrolysis of water.

EXPERIMENT 31.—Spread upon a sheet of tin a piece of paper moistened in a solution of starch and potassium iodide. Press one terminal against the metal sheet, and with the other draw some characters upon the moistened paper. What evidence have you that the potassium iodide has been decomposed?

EXPERIMENT 32.—Repeat Exercise 29, and immediately after disconnecting the battery, place an electric bell in the circuit in its stead.

Storage batteries.

## B. *Heating Effects*

EXPERIMENT 33.—Send the current through two or three inches of fine iron or German silver wire wound around the bulb of a thermometer or touching a cake of paraffin.

EXPERIMENT 34.—Connect the copper and the zinc of the cell used in Experiment 25. Take the temperature of the liquid, and while the zinc and copper remain connected note the behavior of the thermometer from time to time.

## C. *Magnetic Effects*

Recall Experiments 27 and 28.

Experiment 35.—While passing a current through a small helix of wire, test it for magnetism by bringing it near to a magnetic needle.

Experiment 36.—Place an iron core inside the helix and close the circuit. For evidence that the iron core is magnetized, present it to some bits of iron.

Experiment 37.—Label one end of the helix *n*, and decide which end of the wire must be connected with the positive pole of a battery. Send the electric current through the helix, and by means of the compass needle determine whether your prediction is correct. Record your prediction before the experiment, and the result afterward. Place the iron core inside the helix and repeat the experiment. (The end of the helix around which the current is passing *opposite* to the hands of a watch is the *north* pole. The end around which it is passing *with* the hands of a watch is the *south* pole.)

Experiment 38.—Examine and trace the path of the current through a telegraph sounder.

Experiment 39.—Examine an electric bell and trace the path of the current through it. Send the current through it so as to make a "single-stroke" bell; a "clatter" bell. Illustrate by diagrams.

Experiment 40.—Trace the path of the current through an electric motor.

Experiment 41.—Examine and explain the tangent galvanometer.

## IV. **Electrical Measurements.**

In all measurements where a tangent galvanometer is used, throw in enough extra resistance to bring the deflection of the needle below 45°. Slight changes in resistance will then be more readily detected by the needle. Why is this true?

EXPERIMENT 42.—Measure by means of a micro-caliper the diameter of each of the specimens of wire furnished you, and determine its number by referring to the table on page 78. Test your result by using a wire gauge.

EXPERIMENT 43.—Find the resistance, and from that calculate the length of wire on each of several spools containing wire of known number and known material. Proceed in the following manner: Pass a current from a single cell through each spool in turn, connecting the spool, a galvanometer (tangent), and a resistance box in series. By means of the latter introduce enough extra resistance to bring the deflection of the needle to a point below 45°. Note the deflection. Remove the spool from the circuit, and the galvanometer needle will be deflected more than when the spool was in circuit. Add resistance enough to send the needle back to its former deflection, and the amount of resistance added will be that offered by the wire upon the spool.

Suppose it were found that the wire (known to be copper No. 24) on one spool offered 0.5 ohms resistance. Then, as resistance varies as the length (see text-book for laws of resistance), and as it takes 39 feet of No. 24 copper wire to offer a resistance of 1 ohm (see data on page 77), it must take 0.5 of 39 feet to offer 0.5 ohms resistance.

EXPERIMENT 44.—Calculate the resistance of your galvanometer, containing wire of known number and material. Measure the diameter of the coil, and from that compute the length of the number of turns of wire (see data on page 77).

Suppose the wire were No. 22 (diameter 25), and that the length of wire were found to be 24 feet. Then as resistance varies inversely as the square of the diameter, and as it takes 39 feet of No. 24 copper wire (diameter 20) to offer a resistance of 1 ohm, it is obvious that it will take $\frac{25^2}{20^2}$ of 39 feet of No. 22 wire to offer a resistance of 1 ohm, or about 60 feet. Then 24 feet of this wire will offer $\frac{24}{60}$ of 1 ohm, or about 0.4 of an ohm resistance. Test the calculated result by sending a current through the galvanometer connected with another galvanometer. Treat the first galvanometer as though it were one of the spools in Experiment 43, and find its resistance. Compare this result with the calculated result.

Experiment 45.—Find the internal resistance of your battery cell by connecting it with the galvanometer and a known amount of extra resistance (say 2 ohms), and noting the deflection of the needle. Refer to the table of tangents (page 78), and find what deflection of the needle indicates one half the current that is now passing. Add resistance until the needle is deflected to this point. If the current has been decreased to one half, the resistance has been doubled.

For example:

Let $x$ = internal resistance of cell.
" .4 = resistance of galvanometer.
Let 2 ohms = extra added resistance.

Then suppose $x + .4 + 2$ deflects galvanometer to 45°.

Tangent of 45° = 1.000.
½ " " " = 0.500.

Deflection represented by tangent .5 = 27°.
Now add resistance, and suppose

$x + .4 + 2 + 2.6$ deflects galvanometer to 27°.

Then

$$\begin{aligned} x + .4 + 2 &= 2.6 \\ x &= 2.6 - 2.4 \\ x &= \ .2 = \text{internal resistance of battery cell.} \end{aligned}$$

Experiment 46.—By comparing with some standard, find how much your galvanometer needle is deflected for 1 ampère of current, then by referring to the table of tangents make a table showing what strength of current is indicated by the deflection of your needle for each degree from 85° to 36° when fifteen turns of wire are used upon your galvanometer; also when five turns are used.

Experiment 47.—Make a table showing the electromotive force of your cell in each of the following cases: Use 15 turns of wire; close the circuit through the galvanometer alone; add half an ohm of resistance, add one ohm, add 2, 3, 4, etc., to 10 ohms. Does the E. M. F. vary with the resistance?

From Ohm's law:

$$C = \frac{E}{R}, \text{ therefore } E = R\,C.$$

Experiment 48.—Connect your cell with the voltmeter instead of the galvanometer, adding from 0 to 10 ohms of resistance, and notice whether the E. M. F. varies.

Experiment 49.—Choose two cells which are as nearly alike as possible in E. M. F. Connect them in series and first calculate as nearly as you can the amount of current which they will send through 5 turns of wire on the galvanometer and 2 ohms of added resistance, then close the circuit and find how the result compares with your estimate.

Series arrangement:

$$\frac{(\text{E. M. F.}) \times (\text{Number of Cells})}{(\text{Internal Resistance}) \times (\text{Number of Cells}) + \text{External Resistance}}$$

EXPERIMENT 50.—Connect the cells in parallel and repeat the foregoing exercise, with the exception of the calculation, which it will not be necessary to make, unless the cells are alike in E. M. F. and internal resistance.

Parallel arrangement:

$$\frac{\text{E. M. F.}}{\dfrac{\text{Internal Resistance}}{\text{Number of Cells}} + \text{External Resistance}}$$

EXPERIMENT 51.—Use the ammeter in place of the galvanometer and find out whether these two cells send more current through it when connected in series or in parallel.

(*a*) Without added resistance.

(*b*) With added resistance of 0.5 ohms.

EXPERIMENT 52.—Find about what current is required to operate the pieces of apparatus furnished you. (Electric bell, small motor, electrolysis apparatus, etc.) Knowing the E. M. F. and internal resistance of your cell, the resistance of the galvanometer, and the amount of current indicated by the deflection of the needle, calculate the resistance of the apparatus used. What arrangement of battery is desirable?

EXPERIMENT 53.—Connect two motors with a rubber band. Operate one with a battery and connect the other with the galvanometer to see whether it is producing a current as a dynamo. If so, how much? What is its electro-motive force? How much current is used in the first motor?

## V. Induction.

EXPERIMENT 54.—Examine and explain the telephone.

EXPERIMENT 55.—Examine and explain the magneto-electric machine used for telephone calls.

EXPERIMENT 56.—Operate the hand dynamo and see whether it goes harder when its current is made to do work, such as decomposing water, heating a wire, ringing a bell, operating a motor, etc.

### QUESTIONS

1. How would you distinguish between a *magnetic substance* and a *magnet?*

2. Why do iron filings cling only to the ends of a needle that has been made a magnet ?

3. How is it possible to charge a pith ball positively by using sealing wax and flannel ?

4. Upon what does the electro-motive force of a battery cell depend ? Upon what does the quantity of a current depend ?

5. What is meant by polarization ? What means are taken to prevent it ? Why is it necessary to prevent it ?

6. In the process of electroplating, to what pole is it necessary to connect the object to be plated ? Why ?

7. By means of a compass needle, how would you detect the direction of a current through a wire ?

8. A certain spool containing copper wire No. 24 offers a resistance of 0.2 ohms. What is the length of wire on the spool ? How much current would a battery cell with an internal resistance of 0.1 ohm and an E. M. F. of 0.8 volts send through this spool ?

9. Why is a "series" arrangement of batteries generally desirable ? When would a "parallel" arrangement furnish more current ?

### DATA

39 feet of No. 24 copper wire offers 1 ohm resistance.

Resistance is proportional to length.

Resistance is inversely proportional to the square of the diameter of a wire. Diameter of No. 24 wire is twice that of No. 30 wire, therefore its resistance is one quarter as great.

The resistance of platinum is 6.30 times that of copper, while the resistance of iron is 6.62 and that of German silver is 12.28 times that of copper.

## TABLE OF DIAMETER OF WIRE

Diameter of No. 12 is 80 thousandths of an inch.
13 — 72
14 — 64
15 — 57
16 — 51
17 — 45
18 — 40
19 — 36
20 — 32
21 — 28
22 — 25

Diameter of No. 23 is 23 thousandths of an inch.
24 — 20
25 — 18
26 — 16
27 — 14
28 — 13
29 — 11
30 — 10

## TABLE OF TANGENTS

| Deg. | Tan. | Deg. | Tan. | Deg. | Tan. |
|---|---|---|---|---|---|
| 1 | .02 | 31 | .60 | 61 | 1.80 |
| 2 | .04 | 32 | .63 | 62 | 1.88 |
| 3 | .05 | 33 | .65 | 63 | 1.96 |
| 4 | .07 | 34 | .68 | 64 | 2.05 |
| 5 | .09 | 35 | .70 | 65 | 2.15 |
| 6 | .11 | 36 | .73 | 66 | 2.25 |
| 7 | .12 | 37 | .75 | 67 | 2.36 |
| 8 | .14 | 38 | .78 | 68 | 2.48 |
| 9 | .16 | 39 | .81 | 69 | 2.61 |
| 10 | .18 | 40 | .84 | 70 | 2.75 |
| 11 | .19 | 41 | .87 | 71 | 2.90 |
| 12 | .21 | 42 | .90 | 72 | 3.08 |
| 13 | .23 | 43 | .93 | 73 | 3.27 |
| 14 | .25 | 44 | .97 | 74 | 3.49 |
| 15 | .27 | 45 | 1.00 | 75 | 3.73 |
| 16 | .29 | 46 | 1.03 | 76 | 4.01 |
| 17 | .31 | 47 | 1.07 | 77 | 4.33 |
| 18 | .33 | 48 | 1.11 | 78 | 4.71 |
| 19 | .34 | 49 | 1.15 | 79 | 5.15 |
| 20 | .36 | 50 | 1.19 | 80 | 5.67 |
| 21 | .38 | 51 | 1.24 | 81 | 6.31 |
| 22 | .40 | 52 | 1.28 | 82 | 7.12 |
| 23 | .42 | 53 | 1.33 | 83 | 8.14 |
| 24 | .45 | 54 | 1.38 | 84 | 9.51 |
| 25 | .47 | 55 | 1.43 | 85 | 11.43 |
| 26 | .49 | 56 | 1.48 | 86 | 14.30 |
| 27 | .51 | 57 | 1.54 | 87 | 19.08 |
| 28 | .53 | 58 | 1.60 | 88 | 28.64 |
| 29 | .55 | 59 | 1.66 | 89 | 57.29 |
| 30 | .58 | 60 | 1.73 | 90 | Inf. |

# LIGHT

I. LIGHT IN STRAIGHT LINES.
  *Law of Inverse Squares.*
    Experiments 1 and 1a. Fig. 1.
  *Visual Angle.*
    Fig. 2.
  *Light through Small Apertures.*
    Experiment 2. Fig. 3.
  *Shadows.*
    Experiment 3 and Exercise 4. Fig. 4.

II. REFLECTION OF LIGHT.
  *Plane Mirrors.*
    Experiment 5, and Exercises 6, 7, and 8. Figs. 5, 6, 7, 8, and 9.
  *Curved Mirrors.*
    Experiment 9, and Exercises 10, 11, 12, and 13. Figs. 10, 11, and 12.
  *Phases of the Moon.*

III. REFRACTION OF LIGHT.
  *Index of Refraction.*
    Experiment 14. Fig. 14.
  *Enlarged Images by Refraction.*
    Experiment 15.
  *Lenses.*
    Experiments 16, 17, 18, 19, 20, and 21. Fig. 16.
  *The Spectrum.*
    Experiment 22.

# I. LIGHT IN STRAIGHT LINES*

**Law of Inverse Squares.**

EXPERIMENT 1.—Place a cardboard, *X*, having in it a hole which is either a square 1 inch in diameter, a circle 1 inch in diameter, or a triangle 1 inch on a side, 2 inches in front of a candle flame. Place a screen whose surface is ruled in square inches, 2 inches, 4 inches, and 6 inches behind *X*. Notice how large a portion of the screen is illuminated in each case. Note also the shape of the patch of light. Draw to a scale the square pyramid, the triangular pyramid, or the cone of light to illustrate your experiment. (See Fig. 1.)

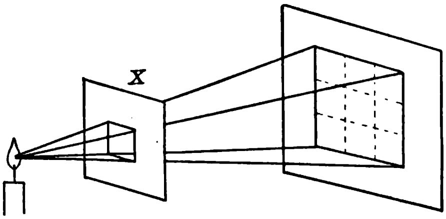

FIG. 1.

It must be remembered that light is going out from the candle flame in all directions, but we are considering only those rays which get through the opening in *X*.

What must be the relative intensity of the illumination when the screen is held directly behind *X*, 2 inches behind *X*, 4 inches behind *X*?

Where would it be necessary to place one candle in order that it should give as much light as four candles? Test your prediction by an experiment.

What would be the candle power of a light which gives as much illumination at a distance of 20 feet as a candle does at 1 foot?

If an observer were sitting 90 feet from a stage, how large a portion of it would be obscured from him by an object 6 inches broad 3 feet in front of him?

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* Considerable portions of this chapter on light have been taken from Woodhull's First Course in Science, with the permission of the publishers, Messrs. Henry Holt & Co. (New York).

EXPERIMENT 1a.—Repeat Experiment 1, using sunlight in place of the candle, and varying the distance of the screen behind *X*. Try holding the screen several feet back of *X*. Do the rays of sunlight diverge as the rays of light from the candle flame? Why?

### Visual Angle.

In Fig. 2, *m* and *n* represent the upper and lower ends of an object. The angle which the line of light *m e* and *n e* make at the eye, *e*, is called the visual angle. Large objects near to the eye subtend a large visual angle. Large objects far from the eye subtend a small visual angle. How does this help us to estimate the size of an object by its distance from us, and the distance of an object from us by its size?

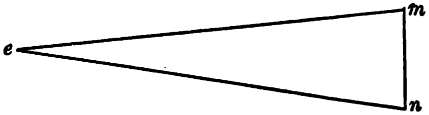

FIG. 2.

The moon is about 240,000 miles distant from the earth and the sun about 92,500,000 miles, but they both subtend for us about the same visual angle. How must their diameters compare with each other?

If in Fig. 2 the lines *e m* and *e n* diverged at the rate of 1 mile in every 114, they would be as far apart as the distance across the moon if extended to the moon. What must be the moon's diameter if it is 240,000 miles distant? What must be the diameter of the sun if it is 92,500,000 miles away, and subtends the same visual angle as the moon?

## Light through Small Apertures.

Experiment 2.—Substitute for cardboard *X*, used in Experiment 1, a cardboard having in it a hole about 0.1 inch in diameter. Hold this about 1 inch from the candle flame, and holding the screen directly behind the cardboard, move it slowly away from it to a distance of about 4 or 5 inches, until a distinct image of the candle flame appears upon the screen. Why is it inverted? Why is it enlarged? (Refer to Fig. 3.)

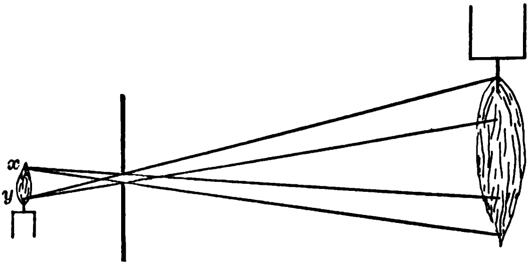

Fig. 3.

What portion of the screen is lighted by the point $x$? By the point $y$? It must be remembered that we are considering only so much of the light from the point $x$ as goes through the opening. Why is it not possible to see around a corner?

Images through keyholes.
Cameras.

**Shadows.**

EXPERIMENT 3.—Repeat Experiment 1, substituting for cardboard *X* the square, circle, or triangle cut from its center. Fig. 4 represents the case in which the square, *c d*, was held 2 inches from the candle flame, and the screen 2 inches behind the square; *a b* represents the candle flame, whose length is estimated to be 1 inch.

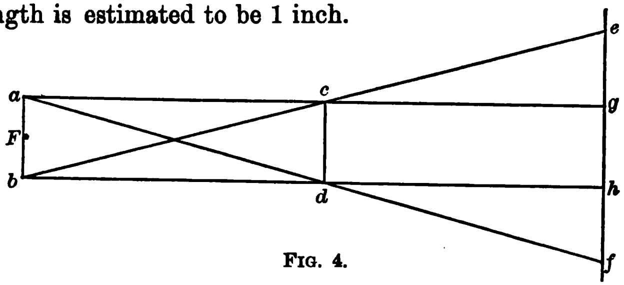

FIG. 4.

What portion of the screen receives no light from the flame? This is called the umbra. What portion receives no light from *a*? From *b*? What about the portions *e g* and *f h*? They are called the penumbra. What about the portions above *e* and below *f*?

What must be the length of the portions *e g*, *g h*, and *h f*?

Suppose the candle flame were reduced to the point *F*, what would be true of the umbra and penumbra?

Shadows cast by electric lights.

What would be the effect on the umbra and penumbra of moving *c d* nearer to or farther from the source of light?

EXERCISE 4.—Draw a figure similar to Fig. 4 to represent the shape of the umbra and penumbra when the source of light is *larger* than the object casting the shadow. Make the candle flame 1 inch long and the object 0.6 inch.

What must be the shape of the moon's and the earth's shadows as cast by the sun?

About how long must their shadows be if the diameter of the sun is 860,000 miles?

Eclipses.

# II. REFLECTION OF LIGHT

**Plane Mirrors.**

EXPERIMENT 5. PART 1.—Fig. 5 represents a piece of bright tin or nickel, which may serve for a mirror; *c d* is a scratch on its face perpendicular to *a b*, its base. Set the mirror on a blank page and draw a line along its base, marking the point *d* where the line *c d* touches the paper. Draw a perpendicular, *d g*, from the point *d*, and extend it about 2 inches.

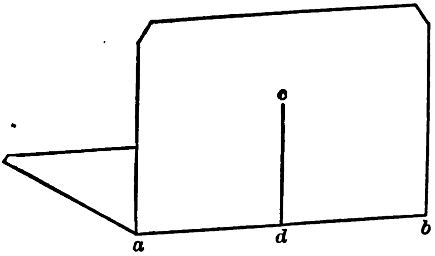

FIG. 5.

Referring to Fig. 6, set up a small object (a pin is convenient) as nearly vertical as possible at any point (*1*) outside of the line *d g*. Place the eye on a level with the paper, and in such a position that the image of this pin shall appear behind the mirror exactly in line with *d*, and set up a second pin in front of the eye so as to appear exactly in line with the image of the first pin and with *d*. Remove the mirror and draw lines from *d* to pins (*1*) and (*2*). Extend each of these lines to exactly the same length, say two inches, and place the letters *f* and *e* at their extremities.

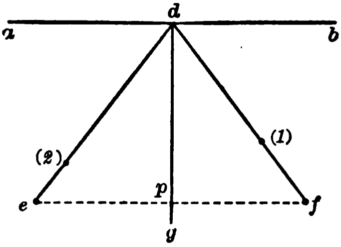

FIG. 6.

Measure as accurately as possible the distance each of these lines has departed from the perpendicular at these points. Record the results after the following manner, calling the distance of *f* from the perpendicular *f p*, and that of *e* from the perpendicular *e p*:

$$\frac{fp}{ep} = \frac{1.65}{1.625} = 1.015 + \text{ (a supposed case).}$$

The angle subtended by *fp* is called the angle of incident, and that subtended by *ep* is called the angle of reflection. Measure these angles in degrees with a protractor. Repeat the observations and measurements a number of times, changing the positions of the pins each time; average the results, and if you discover any fixed ratio between the angles of incident and reflection, state it as a law.

PART 2.—Make a general statement describing the position which an image seen in a mirror appears to occupy with reference to the position which the object actually occupies.

Test your conclusion, which you should look upon as only an hypothesis until it has been tested, by replacing the mirror and pin (*1*) to the first position, and place the eye so that the image of the pin shall be seen in the mirror a little one side of the line *c d*. Hold the eye rigidly in position and make two or three pin-pricks upon the page between the eye and the mirror to mark the direction from the eye to the position of the image (*1'*). Repeat this for two or three positions. Remove the mirror and draw lines through the pin-pricks to *a b* and extend them in the same direction behind the mirror by dotted lines. Do these all pass through the same point behind the mirror? So long as the object (*1*) remains stationary, however much the eye may move, does the position of the image (*1'*) remain fixed?

EXERCISE 6.—Applying the principle which you have just laid down, complete the diagram (Fig. 7) without the aid of the mirror or pins, showing where the image of the object *m n* would appear behind the mirror *a b* when the eye is stationed at *e*. Draw the lines of light from the extremities *m* and *n* of the object to the eye, *e*, showing at what points they are reflected from the mirror. Represent the angles of incident and reflection made by each ray of light. Extend the lines of vision to the extremities *m'* and *n'* of the image.

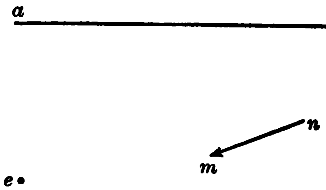

FIG. 7.

Having drawn the figure as you think it ought to be, test its correctness by using the mirror and an object and applying them to the figure; in which case, of course, it will be impossible to put the eye at *e*, but it may be put farther back in the direction of *n' e*, and when it is found what position the image of the point *n* occupies, the eye may be moved so as to look in the direction *e m'*, and thus the position which the image of the point *m* occupies may be found. Pins may be set up at *m* and *n* to represent the extremities of an imaginary object, or a sliver of wood may be cut the proper length and laid upon the figure *m n*.

Does the image of an object seen in a mirror appear to be inverted or reversed? Try holding a printed page before a mirror.

Exercise 7.—Suppose you live at *e* (Fig. 8), and across the street at *a b* is a show window which serves as a mirror; *m n* is a street car passing up the avenue. Complete this diagram, showing where the image *m′ n′* will appear to be located, and showing the direction in which the image will appear to be moving.

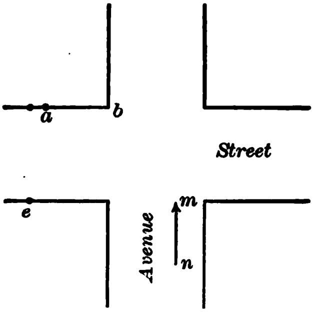

Fig. 8.

Where must a placard be hung upon the show window to hide the point *n* from your vision?

Exercise 8.—*m n* (Fig. 9) represents a lead pencil which you hold in your mouth so that an end projects on either side; *e* represents the position of one of your eyes, the other being closed meanwhile; *a b* is a mirror in which you see the image of the lead pencil. The purpose of holding it in your mouth is to insure that it shall be about the same distance as your eye from the mirror while you are taking the observation. Cut a strip of paper just long enough to hide the image of the pencil when laid upon the mirror.

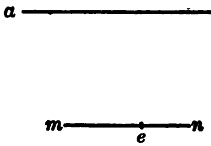

Fig. 9.

What difference would it make in the result if your eye were nearer to or farther from the mirror than the pencil was? Try it by tipping your head back and forth while performing the experiment.

How long and broad must a hand mirror be to just show your whole face?

What is the shortest mirror in which you may see your whole person?

Does your distance from the mirror make any difference with the result?

### Curved Mirrors.

EXPERIMENT 9.—Repeat part 1 of Experiment 5, using a strip of tin, nickel, or other bright metal, curved so as to form the arc of a circle with a radius of about 6 inches. Try both the concave and convex side of the mirror. State whether the ratio between the angle of incident and reflection is the same for curved as for plane mirrors.

EXERCISE 10.—Suppose *c c‴* (Fig. 10) is the arc of a circle of which *d* is the center, and the curved mirror is placed upon this arc, an object is placed at *m n* and the eye at *e*. The ray of light from *m* is reflected to the eye at the point *c*, that from *o* at *c′*, from *p* at *c″*, and from *n* at *c‴*. Complete the diagram, making it show the position of the image *m′ o′ p′ n′*, its shape and its size; also the angles of incident and reflection for each of the four rays. Measure these angles with your protractor to determine whether the figure is correct. Test the truth of your conclusion by holding the curved mirror before your face and bringing a small object, *m n*, between your face and the mirror.

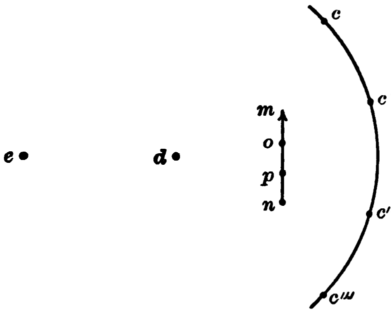

FIG. 10.

EXERCISE 11.—Turn the mirror about, using still the concave side, so that the plane of the curve shall be vertical, and moving it to and fro before the face, watch the changes in your image continually. Let *m n* (Fig. 11) represent a vertical line across the face, *e* the position of the eye, *a b* the mirror, *d* the center of the curve, and *c* and *c'* the places upon the mirror where the rays of light from the points *m* and *n*, respectively, are reflected to the eye. Complete the diagram, showing, by lines, the courses which rays of light from *m* and *n* must take in order to reach the eye by reflection from the mirror, showing also the position and relative size of the image *m' n'*.

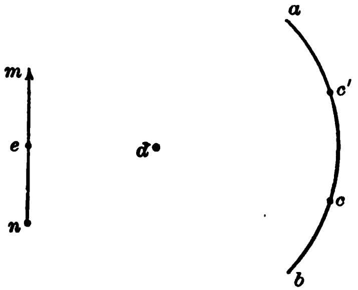

FIG. 11.

The mirror, as you have just used it, was curved vertically, but straight horizontally. Does it give a direct or an inverted image? When near to or far from the face? Does it give an enlarged or a diminished image? Is the image affected horizontally in the same way as it is vertically? Suppose it were concave in all directions like a portion of the shell of a sphere—i. e., like a lamp reflector—in what respect would it give different images from those you have just obtained? Try it with a lamp reflector.

EXERCISE 12.—Turn the convex side of the tin mirror used in the previous exercises toward your face with the plane of curvature vertical. Move it to and fro, noting as before changes in the appearance of the image. Complete diagram 12, in which *m n* represents a vertical line across the face, *e* the eye, *a b* the mirror, *d* the center of curvature, *c* and *c′* the places upon the mirror where the rays of light from the points *m* and *n*, respectively, are reflected to the eye. Show by lines the courses which rays of light from *m* and *n* take in order to reach the eye by reflection from the mirror. Show also the position and relative size of the image *m′ n′*.

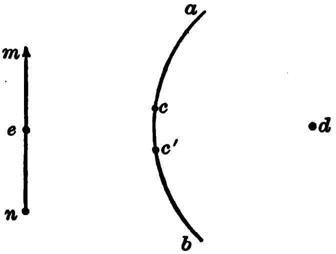

FIG. 12.

Does the mirror as you have just used it give a direct or an inverted image? An enlarged or a diminished image? Is it affected horizontally in the same way as it is vertically? Suppose it were convex in all directions like the back side of the lamp reflector, in what respect would it give different images than those you have just obtained? Examine your face in the bowl of a bright silver spoon, using both the concave and convex surfaces. Why does the image of your face appear long and narrow, or short and broad, as the case may be? When does the image of a straight object appear curved as seen in a curved mirror?

EXERCISE 13.—Place the curved mirror upon a sheet of white paper, and place a lighted candle upon the concave side of it about 6 or 8 inches distant from it. If the candle is a little taller than the mirror, so much the better. Note how the rays of light upon the paper converge to a point. Note the effect of moving the candle nearer the mirror.

### Phases of the Moon.

From what does the moon get its light? Can an object be seen at all unless it either reflects or produces light?

Explain by a diagram the phases of the moon. Designate it as Fig. 13.

## III. REFRACTION OF LIGHT

### Index of Refraction.

EXPERIMENT 14.—Fig. 14 represents the base of a glass cube, such as is used for paper weights; *a* and *o* represent the points where scratches on the face of the cube touch the paper; *b o* is drawn through *o* perpendicular to the opposite sides of the diagram.

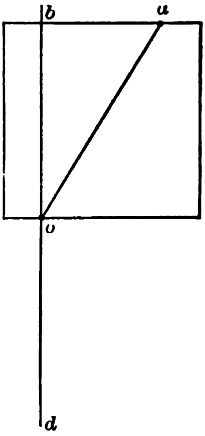

FIG. 14.

Place such a cube in the middle of a blank page, draw the outline around its base, and mark the points *a* and *o*. Remove the cube and draw the perpendicular *b o*, and extend it to a point *d*, so that *o d* shall at least be as long as *o b*. Replace the cube, taking great care to make the lines *a* and *o*, which are drawn upon the glass, stand exactly over the points so marked upon the diagram. Set a pin vertically at *b* and another at any point upon the line *o d*, and place the eye behind it on a level with the plane of the paper. If the apparatus and the drawing are correct, this pin, the line *o*, and the pin *b*, will be seen to be exactly in a straight line. Place the eye in such a position that *a* shall seem to be exactly behind *o*. While the eye is held rigidly in line with *a* and *o*, place a pin in front of it to mark the direction from *o* to the eye. Remove the cube and draw a line from *a* to *o* and from *o* to the pin, and extend this latter line so as to make it exactly equal to *a o*. Mark the extremity of it *e*.

What does the line *a o e* as it appears upon your diagram indicate about the ray of light which passed from *a* to your eye? This is refraction. Was the ray of light which passed in the direction *b o d* refracted? Note that the line *b o d* is perpendicular, and the line *a o* is oblique to the side of the cube. Measure with great care the perpendicular distance from *e* to the line *o d*. Call this *ep*. Also measure the distance from *a* to *b*. Compare these two measurements to find out how much more the line *o e* diverges from the perpendicular *b d* than the line *o a* does. Express it as follows:

$$\frac{ep}{ab} = \frac{\cdots\cdot}{\cdots\cdot} = \cdots\cdot$$

Your measurements will furnish figures to take the places of the dots. This furnishes a means of telling how much a ray of light is bent in passing from one medium into another obliquely to the surface between the two, and is therefore called the *index of refraction*. It differs with different media.

Place a dot a short distance from the cube beyond *a*, where you think a ray of light would pass in taking the course *a o e*. Mark the dot *g*. Then test your conclusion by replacing the cube, putting pins at *g* and *e*, and sighting through to see whether the four points *g*, *a*, *o*, and *e* appear in a straight line. If the position which you first chose for *g* is found not to be correct, mark it $g'$, and mark the position which you select for trial $g''$.

Measure the index of refraction for the ray *g a o* at *a*. Record the results as before.

Formulate a law for the refraction of light as it passes obliquely from air into glass.

## Enlarged Images by Refraction.

EXPERIMENT 15.—Cut a small strip of paper four tenths of an inch wide. Moisten it and stick it lengthwise upon the face of a prism. Let the lower end of the strip of paper extend to the lower end of the prism. Place the prism on end, having the face, marked by the strip of paper, toward the top of the page. Draw an outline around the prism and put dots, *m* and *n*, at the points where the vertical edges of the strip of paper meet the page. Place the eye at the bottom of the page so that *m* shall be seen through one and *n* through the other of the remaining faces. Hold the eye rigidly in position, and make two or three pin-pricks upon the page to mark the path which the ray of light takes in passing from *m* to the eye, and likewise two or three to mark the path of the ray from *n* to the eye. Estimate the width of the strip of paper as seen thus through the prism, and record your estimate. Remove the prism and draw lines from the bottom of the page through the pin-pricks to the outline of the prism, and then to the points *m* and *n* to represent the lines of light. Extend the lines which were drawn from the bottom of the page to the prism, straight through the diagram to the opposite side of it, and mark their extremities *m'* and *n'*. These latter should be dotted lines, to indicate that they represent the *apparent* path which the rays of light took in passing from *m* and *n* to the eye. Measure very carefully the distance *m' n'*. How does it compare with your estimate? Compare it with the distance *m n* thus:

$$\frac{m'\,n'}{m\,n} = \frac{\cdots\cdot}{\cdots\cdot} = \cdots\cdot$$

How many times was the object magnified? Designate this diagram as Fig. 15.

**Lenses.**

EXPERIMENT 16.—*To illustrate how reversed, as well as enlarged images may be produced by refraction.* Use a cylinder of glass about two inches in diameter, or a round bottle containing water. Fig. 16 represents the base of the cylinder which is to be outlined upon a blank page, and the points *a* and *b* represent where lines drawn upon the glass touch the paper. Draw the line *a b*, and through its middle point draw the line *x y* perpendicular to *a b*. Extend it several inches on either side of the diagram. Set up pins at *x* and *y*, and place the eye in such a position that *y* shall appear to be exactly behind *x*. While holding the eye rigidly in this position, make two pin-pricks between the cylinder and the eye to mark the path which the ray of light takes in coming from *b* through the cylinder and then to the eye; also two pin-pricks to mark the path of the ray of light which comes from *a* to the eye. Also make a pin-prick behind the cylinder to mark the path of the ray *e b* beyond *b*, and one to mark *e a* beyond *a*.

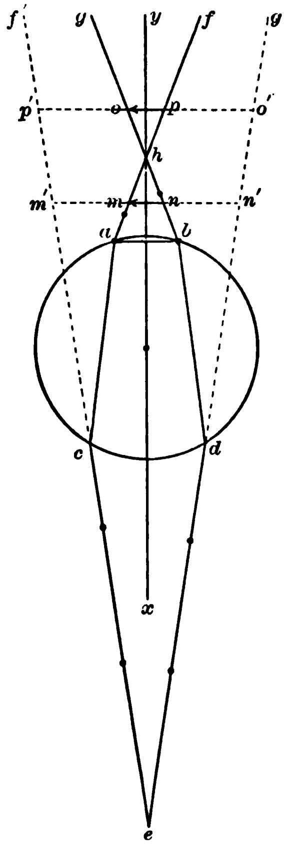

FIG. 16.

Remove the cylinder and draw a line through the pin-pricks from the bottom of the page to the diagram, then to *a* and then through the pin-prick behind *a*. In the same manner draw the line *e d b g*. Note how refraction causes the rays to cross each other beyond the cylinder, or lens. Set up an object at *m n* and see if it appears to extend to *m′ n′* when seen through the lens. Remove the same object to the position *o p*. Does it appear inverted and enlarged as *o′ p′*? If the object is moved nearer to the lens than *m n* or farther from it than *o p*, it does not appear as large. Why? How does it behave in various positions between *m n* and *o p*? Why?

How would you determine the amount of refraction of these rays of light at the points *a*, *b*, *c*, and *d*?

Does this cylinder when in the upright position magnify vertically as well as horizontally? Try it.

The point *h*, where the lines *a m* and *b n* intersect, may be called a focus, and the position which the eye occupied —i. e., the point where these lines of light intersect upon the other side of the bottle—may be called a focus also. How would it affect the position of the focus *h* if the focus *e* were moved nearer to or farther from the bottle? Try it. Foci that are thus the companions of each other are called conjugate foci.

What is a principal focus?

EXPERIMENT 17.—Fill a bottle full of water, cork it, and hold it in the sunlight. Hold a screen a short distance behind it. Is the light converged to a point or a band? Why?

EXPERIMENT 18.—Examine a lens furnished you and predict how it will converge rays of sunlight. Try it.

Measure the distance of the principal focus from your lens. Record it.

EXPERIMENT 19.—Beat together two blackboard erasers in the sunlight, so as to produce a cloud of dust and hold your lens in it. Note how the lens affects the rays of light.

EXPERIMENT 20.—Place a screen facing a window of the room, and on the side of it toward the window your lens at its focal distance. Note a clearly defined picture of objects outside. Place a lighted candle and the lens on the side of the screen which is turned away from the window. Move the lens back and forth until a clearly defined picture of the candle flame is seen upon the screen. Move the candle nearer to the lens. How does it affect the focal distance?

Draw a diagram to illustrate how a lens forms a picture. Call it Fig. 17.

EXPERIMENT 21.—Put a drop of water upon a window pane. Look through it for a picture of the outside world. If the sun is shining upon it, hold a piece of paper behind it and find its focus for sunlight. Similar illustrations can be found in fish globes and in the globes used in drug-store windows.

### The Spectrum.

*To illustrate that light is composed of various colored rays, all of which have different indices of refraction, and hence may be separated by the prism.*

EXPERIMENT 22.—Hold your prism in the sunlight so that its longest axis shall be horizontal and at right angles with the rays of sunlight. Let the further wall of the ceiling of the room act as a screen. Try holding the cardboard screen near the prism. Why is the result so different in the two cases? The patch of light of various colors which is seen upon the wall is called the *spectrum.* Which color is refracted least? Name as many of the colors as you can detect in the order of their refraction.

Place a second prism against the first. What effect has it upon the spectrum? Why? Does the sunlight pass through both prisms? See if you can catch it upon the cardboard screen. Can you use a second prism to disperse still farther the rays which pass through the first prism?

Draw a diagram to illustrate how sunlight is broken in passing through a prism. Call it Fig. 18.

### QUESTIONS

1. Looking out over a landscape, a schoolhouse which was 75 feet high was found to subtend the same angle as a stick 1.5 inches long at a distance of 10 inches from the eye. A tree standing beside the schoolhouse subtended the same angle as the stick held 20 inches from the eye. How far away was the schoolhouse ? How tall was the tree ?

2. Which would give a better light for reading, a ten-candle-power lamp 3 feet from a book, or two gas jets each twenty-candle power 8 feet from the book ?

3. Why are the images of trees and of other objects seen in the water always inverted ?

4. Why is it impossible to have an inverted image of your face in a *convex* mirror ? Under what conditions does the image of a straight object appear curved in either concave or convex mirrors ?

5. When you look into the bowl of a silver spoon why do you never see a direct image of your face ? Why is it always a diminished image ?

6. How is the focus of a curved mirror changed by a change in the position of the source of light ?

7. Why was it that in our experiments with the prism the spectrum appeared only in the last ?

# SOUND

I. How Sound is produced.
  Experiments 1, 2, 3, and 4.
II. How Sound is transmitted.
  Experiments 5, 7, 8, and 9. Exercise 6. Fig. 1.
III. Reflection of Sound—Echoes.
  Exercise 10.
IV. Intensity of Sound and Amplitude of Vibration.
  Experiment 11.
V. Resonators.
  Experiments 12 and 13. Fig. 2.
VI. Pitch.
  Experiments 14 and 15. Exercise 16. Fig. 3.
VII. Sympathetic Vibrations.
  Experiment 17.
VIII. Vibration of Strings.
  Experiment 18.
IX. The Musical Scale.
  Exercise 19.
Questions.

## I. How Sound is produced.

*All sound-producing instruments are in a state of vibration and cause vibration in the air.*

Experiment 1.—Strike a tuning fork, and while it is still producing sound, touch the prongs to the surface of water in a tumbler; touch them to the tip of your tongue; touch them to the edge of an *empty* tumbler.

Experiment 2.—Bring a pith ball against a piano string while it is sounding; against the rim of a bell while it is sounding.

EXPERIMENT 3.—Blow through an organ pipe while holding it near the end of a long glass tube containing cork dust.

EXPERIMENT 4.—Strike a bell while holding it a few inches above a diaphragm upon which cork dust has been sprinkled.

**Tremor of buildings due to vibrations of large organs.**

## II. How Sound is transmitted.

***In order that sound may be heard, air or some medium must extend all the way from the sounding body to the ear.***

EXPERIMENT 5.—Ring an electric buzzer, suspended in a bottle (Fig. 1); exhaust the air, and ring again; allow the air to enter, and ring again; pour in some ether, and after it has evaporated ring again; fill the bottle with hydrogen, and ring again. In which case was the sound most distinctly heard? In which case *least* distinctly?

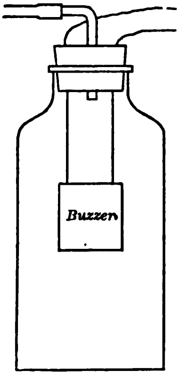

FIG. 1.

EXERCISE 6.—Compare the density of air with that of ether and hydrogen. Predict what would be the effect of ringing the buzzer in a bottle of illuminating gas. In a bottle of carbon dioxide gas.

EXPERIMENT 7.—Submerge a tumbler in a pail of water, and while holding it suspended beneath the surface, strike it with a piece of metal so as to cause it to ring. The sound is transmitted through the water to the air and through the air to the ear.

**Striking stones together under water.**

Experiment 8.—Fasten the opposite ends of a long wire into the bottoms of cigar boxes or large pasteboard boxes, and hold one box against the ear while some one taps upon the box at the further end of the wire. Hold the wire suspended freely throughout its entire length.

The acoustic telephone.

Experiment 9.—Hold one end of a meter stick to the ear while some one scratches with a pin on the other end.

### III. Reflection of Sound—Echoes.

Exercise 10.—How may we calculate the distance of a cliff or other reflecting object by the echo? (Sound has a velocity of 1,100 feet per second.)

Multiple echoes.
Roll of thunder.
Whispering galleries.
Acoustic properties of large audience rooms.

### IV. Intensity of Sound and Amplitude of Vibration.

Experiment 11.—Strike a tuning fork first gently, and then hard, and touch it each time to the sides of a tumbler.

### V. Resonators.

Experiment 12.—Hold a vibrating tuning fork over a tall cylinder about two inches in diameter (Fig. 2) and pour water into the cylinder until the air column has been reduced to such a length that it reenforces the sound of the tuning fork a maximum amount. Measure the length of the air column. When a prong of the tuning fork makes a complete excursion to and fro it

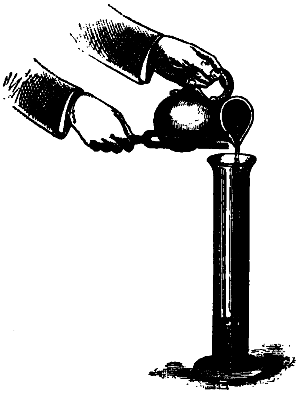

Fig. 2.

is called one vibration. Why does four times the length of air column represent the wave length of the tone of the tuning fork? Knowing the number of vibrations the tuning fork makes per second, how would you calculate the velocity of sound? How do the number of vibrations affect the wave length?

Velocity of sound in air, liquids, solids.
Velocity of sound affected by temperature, moisture, etc.

EXPERIMENT 13.—While a tuning fork is vibrating, bring its stem firmly against the table top.

Sounding-boards.
Provision for resonators in stringed instruments.
Loudness of sound.
Large and small tuning forks.

## VI. **Pitch.**

EXPERIMENT 14.—By blowing through the holes of a rapidly revolving wheel (Fig. 3), or drawing a card rapidly over the teeth of a saw, determine how pitch is related to rapidity of vibration.

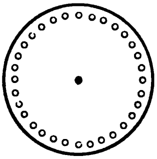

FIG. 3.

EXPERIMENT 15.—By means of a siren and piano, or tuning fork, determine the number of vibrations which correspond to a given tone.

EXERCISE 16.—If a locomotive is rapidly approaching or receding while blowing its whistle, how is its sound affected as to pitch?

## VII. **Sympathetic Vibrations.**

EXPERIMENT 17.—Cause a large tuning fork to vibrate, and rest its stem for a moment upon a resonating box supporting another fork of the same pitch. Remove the first fork and listen for evidence that the second fork has taken up sympathetic vibrations.

## VIII. **Vibration of Strings.**

EXPERIMENT 18.—By means of a sonometer find the relation of pitch to length, thickness, and tension of a wire.

Stringed instruments.
Overtones.
Harmonics.
Quality.

## IX. **The Musical Scale.**

EXPERIMENT 19.—Examine the keyboard of a piano and be able to produce the scale—*do*, *re*, *mi*, *fa*, *sol*, *la*, *si*, *do*—beginning with any given key.

### QUESTIONS AND PROBLEMS

1. Why is it necessary to speak with greater effort to be heard on a high mountain than at the sea level ?

2. Why is it possible to hear so distinctly for a long distance through a speaking tube ?

3. What is an echo ? How far away must a reflecting surface be if sound, which travels at the rate of 1,100 feet a second, returns in 2½ seconds after it is emitted ?

4. What evidences are there that pitch does not affect the velocity of sound ?

5. If sound travels at the rate of 1,100 feet a second, what is the wave length of a note that makes 512 vibrations a second ?

6. Why are the violin, piano, and other stringed instruments provided with sounding-boards ?

7. To what is the sound in wind instruments due ? How does the length of the instrument affect the pitch ?

8. In what respect may sounds differ from one another ? Upon what does the quality of a sound depend ? Illustrate.

9. Why does the addition of furniture and hangings sometimes better the acoustic properties of rooms ?

10. Name some of the principles of sound that are employed in the tuning and the playing of a stringed instrument.

# TYPICAL ENTRANCE EXAMINATION QUESTIONS USED IN AMERICAN COLLEGES IN 1900

*From six to ten questions required. Time allowed, about two hours.*

(*a*) Explain why raindrops are spherical. (*b*) The simultaneous fall of bullet and feather in a vacuum. (*c*) Why oil which floats in water will sink in alcohol. (*d*) Why a suction pump will not draw water from a depth of 50 feet.

(*a*) Define energy. (*b*) What is the immediate source of energy in a water wheel, a clock, a dynamo? (*c*) Define the unit of work. (*d*) State the relation of machines to energy.

Give an example of each of the three states of matter, with a reason for the classification assigned.

What is meant by the moment of a force? Explain concisely why such a quantity is useful, and apply the principle in order to explain the value of the lever as a mechanical instrument.

Explain the distinction between mass and weight. Why does a body weigh less at the equator than at the pole? How could you find two equal masses?

State the law known as "the parallelogram of forces."

Define moment of force. What force in pounds applied at one end of a lever 10 feet long will lift a weight of 250 pounds at the other end, when the fulcrum is 2 feet from the weight end?

What are the units of mass, length, and volume in the metric system? How are they derived?

What is the relation between mass, volume, and density? State the difference between density and specific gravity.

How much work is done in lifting 5 kilos vertically through 500 cubic centimeters? State unit used.

What is the length of a pendulum beating seconds? ($g = 980.5$ cubic centimeters.)

Define what is meant by the center of gravity of a body.

What will be the velocity of a free falling body at the end of the fourth second?

How far will a body fall free during the fifth second of its descent?

(*a*) Give one method of finding the density of a liquid.

(*b*) A floating cube of wood, 3 centimeters on a side, displaces 20 cubic centimeters of water. Find the density of wood.

Explain the principle of a barometer. How does a water barometer differ from the common mercurial barometer?

Find the volume of air at a pressure of 76 centimeters which will become 50 cubic centimeters under a pressure of 165 centimeters.

How can the pressure of the atmosphere be demonstrated?

Why does a body weigh less when immersed in water than when it is in the air?

Upon what does the pressure of a liquid against the walls of a vessel depend?

What is the law of Boyle and Mariotte?

Describe Torricelli's mode of making a nearly perfect vacuum.

What are the fixed points of a thermometer, and how are they determined?

A brass rod at 0° is 1 meter long. What is its length at 100°, if the coefficient of expansion for brass = .00002?

Upon what does the boiling point of water depend? (Explain.) A mass of 200 grams of a solid at 100° is dropped into 500 grams of water at 10°, raising the temperature of the water to 13.5°. Find the specific heat of the solid.

(*a*) State the effects produced in water by rise in temperature from −5° to 100° C. (*b*) Define coefficient of expansion. (*c*) Define specific heat. (*d*) What is the mechanical equivalent of heat?

If heat be applied uniformly to ice initially at −10° C. until the temperature of the substance has risen to 15° C., what different effects will be noted, and what relative times will have been occupied in each process?

What general relation exists between the coefficients of thermal expansion of solids, liquids, and gases?

How is a mercurial thermometer made?

What is the relation of the Fahrenheit to the centigrade thermometer scale?

What is meant by specific heat? What substance is taken as the standard?

(*a*) State laws of magnetic attraction. (*b*) What is magnetic declination? (*c*) State how a body may be electrified without contact. (*d*) State defects in a simple galvanic cell and how remedied.

Show carefully how a Leyden jar is charged and discharged. What is the principle of the electro-magnet? Upon what does the strength depend?

Describe some simple experiments which would prove the laws of electrostatic attraction, and derive the unit of electricity therefrom. How is an electroscope charged by induction?

Explain the action of a galvanic cell. What is the difference between a Daniell and a Le Clanche cell?

What is the principle of the galvanometer? Describe one form.

State Ohm's law, and give an illustration of its use.

Explain in your own words the meaning and importance of Ohm's law. How can it be utilized to find the magnitude of the resistance of a given wire?

A battery of 15 cells in series sends a current through a galvanometer whose resistance is 10 ohms. If the potential difference and resistance of each cell are respectively 1.1 volts and 3 ohms, what current will be indicated?

Give an account of the action called electrolysis and of the laws which it obeys.

Describe some simple experiments which would illustrate the behavior of electro-magnetic induced currents of electricity. Show (using diagrams) that the action of the dynamo is based on an application of the laws of those induced currents.

Explain the principle of the secondary or "storage" cell.

Explain the construction and operation of the telephone.

What is the effect of a current of electricity upon a magnetic needle?

Describe a simple circuit for the Morse telegraph.

What are lines of force around a magnet?

Describe a two-liquid Voltaic battery.

(*a*) State laws of propagation of light. (*b*) Draw an image produced by a plane mirror. (*c*) Draw an image produced by a convex lens. (*d*) Define dispersion, conjugate foci, virtual image.

Tell how light is propagated. Show by diagram what is meant by index of refraction.

How is a spectrum formed? Upon what does the color of light depend?

Define principal focus of a lens. Draw diagram showing the formation of an image by a double convex lens when the object is outside the center of curvature. (Give reasons for your sketch.)

What two effects may be noted when light is passed through a prism, and what explanation may be given of them?

Explain how an image is formed by a concave mirror. When will the image be erect, when magnified, and when virtual?

How do spectacle lenses correct some common defects of vision?

What is the cause of color in bodies? What are complementary colors? Explain why the effect produced on mixing two colors is different from that produced on mixing two pigments of the same two colors.

Make a diagram illustrating the formation of an image by a concave mirror.

Make a diagram showing the formation of an image by a convex lens.

How are sound vibrations compounded? What is meant by the *interference* of sound waves? Show how the principle of interference accounts for consonance and dissonance in music.

(*a*) Explain the propagation of vibrations through air. (*b*) Define a wave length. (*c*) Explain echo. (*d*) What is the velocity of sound in air, and how determined?

What is meant by resonators in the study of sound? Discuss the apparent increase in the energy of the sound due to the presence of the resonator. What practical use is made of resonators?

How may each of the notes of the scale be successively produced on a single stretched cord?

What are the three characteristics of sound, and upon what does each depend? What are beats?

How can the velocity of sound in air be determined?

What are "overtones" and "harmonics"?

# REFERENCE LIST OF EXERCISES, QUESTIONS, PROBLEMS, LAWS, FORMULAS, TABLES, DATA, ETC.,

*To be found in Henderson and Woodhull's Text-book of Physics, and Woodhull and Van Arsdale's Laboratory Manual.*

## PROPERTIES OF MATTER AND MECHANICS OF SOLIDS

1. Exercises, Questions and Problems.
   Text-book, pp. 6, 14, 41, 52, 58, 63, 69, and 85.
   Manual, pp. 2, 3, 5, 8, 10, 11, 12, 13, 14, 15, 16, and 17.
2. Laws of Motion.
   Text-book, p. 72.
3. Formulas.

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| Machines | “ | pp. | 76–84 |

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| Metric | “ | “ | 25 |
| Densities | “ | “ | 42 |
| Specific gravity of gases | “ | “ | 44 |
| Equivalents—English and metric systems | Manual | “ | 17 |

5. Units of C.-G.-S. System. Text-book, p. 52.

## MECHANICS OF FLUIDS

1. Exercises, Questions and Problems.
   Text-book, p. 116.
   Manual, pp. 20, 21, 24, 27, 32, 34, 35, 36, 37, 38, 39, 40, 41, and 42.

2. Law of Boyle. Text-book, p. 112.
3. Formulas for area of circle, volume of cylinder, and volume of sphere. Manual, p. 42.
4. Table of specific gravity, weights, equivalents, etc. Manual, p. 42.
5. Weight of a litre of hydrogen. Text-book, p. 106.

### HEAT

1. Exercises, Questions and Problems. Manual, p. 61.
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### MAGNETISM AND ELECTRICITY

1. Exercises, Questions and Problems. Manual, p. 77.
2. Laws

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| Of inverse squares | Text-book, | pp. | 219, 227 |
| “ Ohm | “ | p. | 260 |

3. Formulas

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| For magnetite | Text-book, | p. | 209 |
| “ chemical action in Voltaic cell | “ | “ | 238 |
| “ battery solutions | “ | pp. | 242–244 |

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| For Ohm's law | Text-book, | p. 260 |
| “ Wheatston bridge | “ | “ 266 |
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| “ specific resistance of metals to electric currents | Text-book, | “ 268 |
| “ diameter of wire | Manual, | “ 78 |

5. Essentials of the Voltaic cell. Text-book, 238.

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| Tangents explained | Text-book, | p. 262 |
| Essential elements of a dynamo | “ | “ 280 |
| Data for calculating resistance | Manual, | “ 77 |

## LIGHT

1. Exercises, Questions and Problems. Manual, pp. 83, 86, 87, 88, 89, 90, 91, 92, and 98.

2. Laws

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| Of inverse squares | Text-book, | p. 293 |
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Total number of experiments in the laboratory manual, 182.

Total number of figures in text-book, 259; in manual, 109.

Examination questions for entrance to colleges. Manual, p. 105.

Total number of exercises, questions, and problems in text-book and manual suitable for examination purposes, 214.

THE END

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